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Cold Regions Research and Engineering Laboratory

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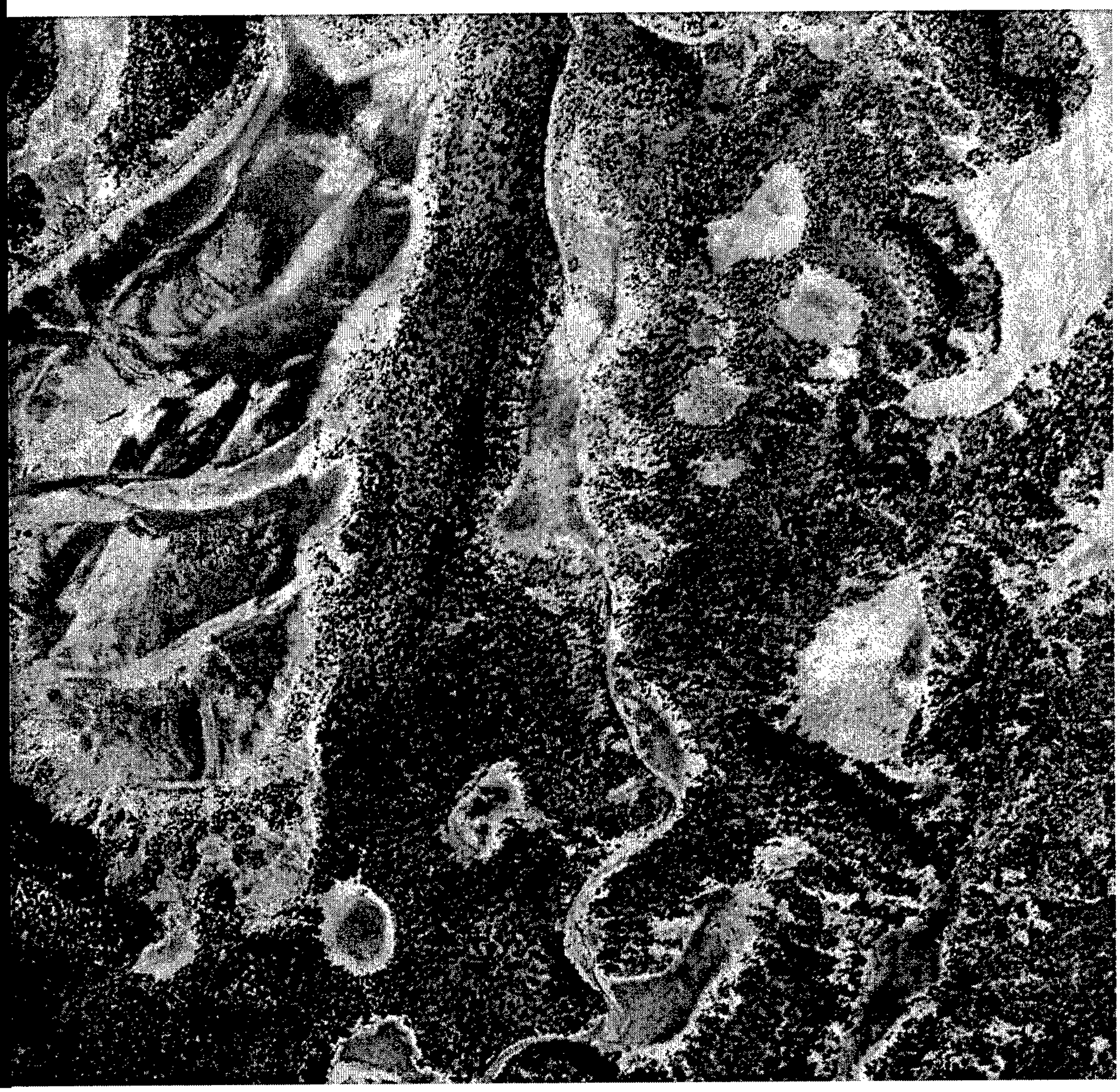
Engineer Research and Development Center

Lake Thompson, Mojave Desert, California

A Desiccating Late Quaternary Lake System

Antony R. Orme

January 2004



Front cover: High-resolution aerial photograph taken northwest of Buckhorn Playa showing stabilized dunes adjacent to exposures of the Pleistocene Lake Thompson lakebed as small playas. The photography was obtained during a NASA research flight collecting LIDAR topographic data for CRREL.

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Clay-mineral analysis by Richard Yuretich

Prepared for EDWARDS AIR FORCE BASE

ABSTRACT

In late Pleistocene time, Lake Thompson rose to 710 m above sea level and covered 950 km^2 of the western Mojave Desert, California. During Holocene time, the lake desiccated and is today represented mainly by Rogers, Rosamond, and Buckhorn Dry Lakes, which cover 200 km^2 of Edwards Air Force Base. Elsewhere the former lake basin is characterized by exposed lake beds and beach ridges or mantled by aeolian and fluvial deposits. This study reports on the spatial and temporal components of former Lake Thompson. The spatial dimension identifies seven major geomorphic and lithostratigraphic units within the former lake basin, of which the most important are the modern playa, former lake system, aeolian mantle, interfingering fluvial deposits, and various bedrock outcrops. These units and their subdivisions are presented on a map entitled Geomorphology and Quaternary Geology of Lake Thompson within Edwards Air Force Base, California. The temporal component is represented by a chronology of Lake Thompson based on accelerator mass spectrometry dating of the stratigraphic sequence. Although a former deep lake beneath the modern dry lakes had long been inferred from borehole data, its age and development remained unknown. The present study recovered four cores for stratigraphic and sediment analysis and dating. Ages for the deep lake range from 30,000 to 17,000 BP, a humid interval typified by frequent inputs of fluvial sediment. After 17,000 BP, the lake began to desiccate, and its exposed floor was lowered by deflation. However, shallow perennial lakes returned during latest Pleistocene and early Holocene time, prior to the present phase of desiccation. Clay minerals from the cores support this scenario. High smectite values reflect deposition in a large lake under humid conditions around 30,000 BP, followed by diminishing smectite as conditions became drier. A more saline, alkaline lake existed under drier climatic conditions before 30,000 BP. The later phases of lake devolution during Holocene time have seen lake segmentation as shallow-water waves and currents generated a sequence of beach ridges around contracting lakes. These ridges became mantled with aeolian sand, but as fluvial sediment inputs diminished, these dunes were degraded and their sand removed downwind. The roots of these dunes survive as yardangs. Understanding this complex system provides a valuable tool for management of the lake basin, including its flood hazards, groundwater resources, blowing dust potential, subsidence problems, and ecology.

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PREFACE

This report was prepared by Dr. Antony R. Orme, Professor of Geography, University of California, Los Angeles. The clay-mineral analysis was done by Richard Yuretich, Professor of Geology, University of Massachusetts.

Funding for this project was provided to the Environmental Laboratory and the Cold Regions Research and Engineering Laboratory, both part of the U.S. Army Engineer Research and Development Center, by Edwards Air Force Base, California. Dr. Robert Lichvar, Research Ecologist, CRREL, was the principal investigator. Lawrence Gatto and Dr. Daniel Lawson, both of CRREL, provided technical reviews.

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Lake Thompson, Mojave Desert, California:

A Desiccating Late Quaternary Lake System

ANTONY R. ORME

1 INTRODUCTION

The Basin and Range Province of western North America contains numerous internal drainage basins that contained lakes during wetter intervals of the Pleistocene Epoch. These lakes have all decreased in volume during the drier Holocene Epoch, and many have desiccated entirely. These lake systems have long attracted scientific interest, notably in the classic studies of Lakes Bonneville and Lahontan by Gilbert (1890) and Russell (1885), respectively, and in the early studies of saline deposits by Gale (1913) and mammaliferous lake beds by Buwalda (1914). More recently, renewed interest in climate change and water resources has stimulated fresh studies of many lakes, supported by a wide range of exploratory, analytical, and dating techniques [see Orme (2002) for a recent review].

Lake Thompson in the western Mojave Desert of California is one such Pleistocene lake that has desiccated during the Holocene but that, until now, has not been the focus of much sustained research, in part because its subtle surface features excite little interest, in part because it lies mostly within the restricted confines of a major aerospace facility, Edwards Air Force Base (AFB). Such investigations as have occurred have been concerned mostly with groundwater resources, aquifer compaction, and related surface subsidence, especially with respect to aerospace operations. This report presents the results of recent investigations on the late Quaternary devolution of Lake Thompson, focusing on the changing geomorphology, sedimentology, and chronology of the desiccating system.

2 REGIONAL SETTING

Geomorphology and Geology

At its greatest extent during late Pleistocene time, Lake Thompson covered about 950 km^2 of the Antelope Valley in the far western Mojave Desert (Fig. 1). It was comparable in area to Lake Searles (914 km^2) but larger than Lake Owens (531 km^2) in the Eastern California Lake Cascade farther north. During its last highstand, during late Pleistocene time, Lake Thompson reached 710 m above sea level and may have spilled occasionally northward into the closed Fremont Valley to feed Koehn Lake, whose now mostly dry surface lies around 575 m above sea level. The center of former Lake Thompson lay near the southeast margin of Rosamond Dry Lake. Prior to the results presented in this report, the chronology of Lake Thompson was unknown, other than a consensus that a deep lake of uncertain age existed in Pleistocene time and desiccated in the Holocene.

Today, following Holocene desiccation and widespread progradation of alluvial and aeolian deposits, 20% of the floor of Lake Thompson survives in two significant dry lakes, Rogers in the east and Rosamond in the west, separated by a suite of smaller dry lakes, of which Buckhorn is the largest. These lakes, with a mean surface elevation of 692 m, are normally dry but may be flooded to shallow depth during occasional storm events. The bare playa surface of Rogers Dry Lake, covering 130 km^2, is somewhat rectangular in shape, with a longer north–south axis measuring 20 km and a shorter east–west axis of about 10 km. Its western margin is transgressed by the lobate fan delta of Mojave Creek. Rosamond Dry Lake presently covers about 57 km^2, and its bare playa surface is roughly circular, with a diameter of about 9 km. Buckhorn Dry Lake covers up to 10 km^2, with a longer east–west axis of about 4 km.

The remaining 80% of the former lake floor comprises a complex suite of lacustrine, aeolian, and fluvial deposits, floored at greater depth by mainly plutonic rocks, mostly quartz monzonite, which emerge to form low hills to the north and east of the former lake basin. Exposed or veneered lake beds form monotonously flat terrain to the south and west of Rosamond Dry Lake. Abandoned beach ridges and transgressive fluvial deposits occur subtly around the margins of all the dry lakes, while aeolian sands have accumulated extensively downwind (eastward) of Rosamond and Rogers Dry Lakes.

Lake Thompson and its relict dry lakes occupy a triangular drainage basin of 5633 km^2. To the southwest, beyond the dextral San Andreas fault zone, rises a massif of Precambrian and Mesozoic igneous and metamorphic rocks forming the San Gabriel Mountains (2865 m) and their westward extension (Fig. 2). To

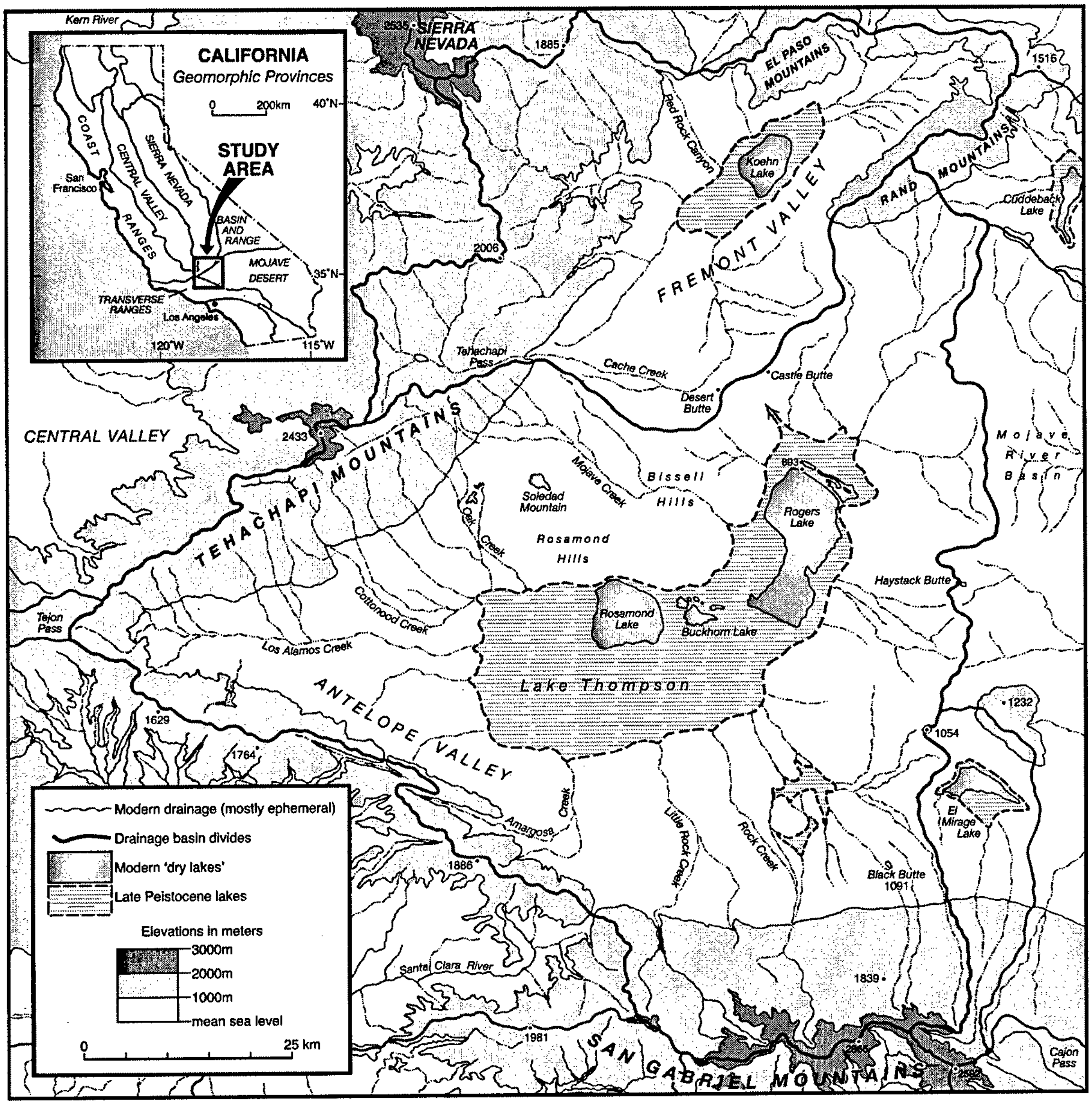


Figure 1. Lake Thompson in its regional setting.

the northwest rise the Tehachapi Mountains (2433 m), a Mesozoic granitic mass disrupted by the sinistral Garlock fault zone. To the east, low granitic hills rise to 1000 m from beneath Quaternary fanglomerates. Low domes of Mesozoic granitics, mostly quartz monzonite, also outcrop within the basin, notably in the Rosamond and Bissell Hills, but otherwise the Antelope Valley is extensively mantled by Quaternary lacustrine, fluvial, and aeolian deposits. Displacements of the western Mojave block between the active San Andreas and Garlock fault

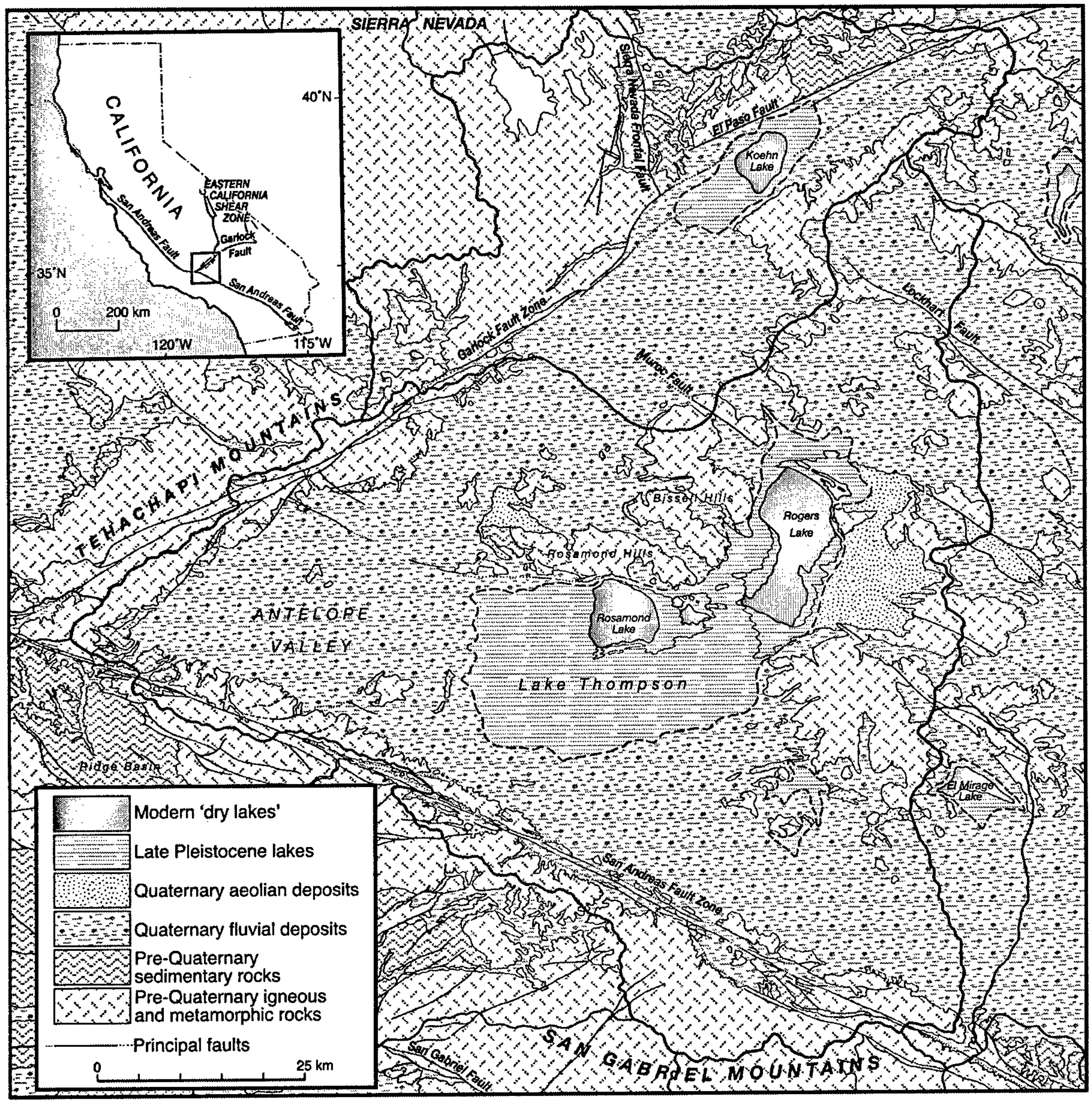


Figure 2. Lake Thompson in its geological setting.

zones, as well as Neogene volcanism and dislocation along northwest-trending faults within the basin, are important elements in the late Cenozoic evolution of this region, but, although recent deformation due to groundwater extraction occurs, no clear evidence has yet emerged for tectonic dislocation within the late Quaternary deposits of Lake Thompson.

Hydroclimatology

During late Pleistocene times, Lake Thompson was fed at least seasonally by runoff from the San Gabriel and Tehachapi Mountains, mostly down Rock, Little Rock, Amargosa, Los Alamos, Cottonwood, Oak, and Mojave Creeks (Fig. 1). Today, these creeks rarely flow beyond the mountains, due in part to climate, in part to drainage diversions and impoundments. However, creek flows may still reach the former lake floor during unusually wet spells, such as the 1982–1983 El Niño event, when Little Rock Creek in particular flooded into Rosamond Lake.

Although higher precipitation and lower temperatures prevail in the nearby mountains, the present climate of the Antelope Valley is essentially arid and seasonally hot. For the period 1973–1994, Lancaster at the southwest corner of the former lake recorded a mean annual precipitation of 203 mm, while Edwards AFB to the northeast recorded 169 mm, mostly from winter cyclonic activity but also from local summer thunderstorms (Bach et al. 1996). Mean annual evapotranspiration is 2800 mm.

Winter rainstorms, related to eastward-moving cyclonic systems from the Pacific Ocean, and summer thunderstorms, related to moist monsoonal flows moving northward from the Gulf of California and neighboring tropical Pacific, may sometimes inundate the dry lake beds. The duration of flooding depends on the magnitude and location of precipitation cells and ambient climatic conditions over the lakes. Significant temporary flooding may be associated with El Niño conditions, when unusually warm surface waters of the eastern Pacific Ocean favor the onshore movement of very moist air masses and lead to locally heavy precipitation, as occurred over the region during the 1982-83 and 1997-98 water years. These seasonal floods may in turn introduce modest amounts of fresh fluvial sediment to the system, notably to Rosamond Lake, and modest shallow-water waves may rework shoreline deposits into swash bars a few centimeters high. These features are, however, negligible in comparison to the larger bars and barriers formed during the higher lake stands and wave action of the wetter past.

Vegetation and Land Use

As a result of the prevailing aridity, vegetation is sparse and, beyond the bare floors of the dry lakes, is dominated by a 5–30% cover of low saltbush scrub, mostly *Atriplex* and *Artemisia* species interspersed with various grasses, with *Yucca brevifolia* (Joshua tree) on sandy ridges and chenopod scrub near alkali sinks (Lichvar et al. 1997).

Location and exposure are important variables in the relationship between surficial geology and vegetation. Thus, the western or upwind shores of the relict

dry lakes are characterized by more lacustrine and fluvial facies, less-sorted sediment inputs, and higher soil moisture, all of which are reflected in the vegetation. In contrast, the eastern or downwind shores are typified by more beach and aeolian facies, better-sorted sands and gravels, and reduced soil moisture. Nearly everywhere, however, aeolian deposits are in a degraded state owing to the reduced sand supply of late Holocene time; this is reflected in variably lithified sandscapes and yardangs in which vegetation has difficulty becoming established or surviving.

There has been much disturbance to the natural system by human activity over the past century or more. This is most evident above the western and southwestern shores of Rosamond Dry Lake, where past grazing and tillage practices and the formation of artificial ponds have disrupted or obliterated natural features. Above the western shores of Rogers Dry Lake, military activity and related infrastructure have dominated the past half century. Past clay-mining activities have also disrupted the floors of Buckhorn and Rogers Dry Lakes. Furthermore, interruption of stream flows from the San Gabriel and Tehachapi Mountains and drawdown of artesian water during the past century have significantly decreased the volume of water naturally reaching the former lake plain and its relict dry lakes, enhancing desiccation and aeolian degradation within the basin.

With a sparse vegetation cover, a legacy of human interference, and lowered groundwater tables, wind action remains a significant force in shaping the former lake basin, especially in winter and spring, when winds are at their strongest (Bach et al. 1996). Winds are predominantly westerly, but effective surface winds are strongly controlled by local relief.

3 PAST AND PRESENT RESEARCH.

Past Research

The dry lakes of the Mojave desert were noted by government and railway surveyors in the mid-nineteenth century, and from the 1880s onward the groundwater resources of the Antelope Valley, as well as surface waters from the nearby mountains, began to be tapped for irrigation agriculture and domestic use. By 1890, more than 100 wells were drawing on groundwater beneath the valley (Hinton 1891); by 1909, 353 wells had been drilled (Johnson 1911) and by 1921 the number of wells had reached 500 (Thompson 1929). Significantly, these wells revealed widespread artesian water reserves held in fluvial sands and gravels beneath what are now recognized as mostly impermeable lake beds. Thompson (1929) speculated on the former existence of a perennial lake and its possible links northward to the Fremont Valley and eastward to the Mojave River. Miller (1946) subsequently named this Lake Thompson. Dibblee (1960, 1963) later mapped the general distribution of Quaternary deposits around the surviving dry lakes and identified shoreline remnants around 710 m above sea level. He thought that a late Pleistocene lake at that elevation would have a maximum depth of 15–18 m and cover about 518 km^2. He also identified deformed lacustrine deposits within the Neogene Tropico Group, a volcano-sedimentary sequence exposed in the Rosamond and Bissell Hills and buried at depth beneath the Antelope Valley, that indicate the episodic presence of earlier lakes in the region. A gravity survey showed a maximum depth of over 3000 m to crystalline bedrock southeast of Lake Rosamond, suggesting profound Neogene deformation and probable faulting beneath the valley (Mabey 1960).

In the 1950s, surface subsidence, sinkholes, and giant desiccation cracks (>1 m wide, >5 m deep) began posing problems for military and aerospace operations on the dry bed of Lake Rogers. These features, attributable to aquifer compaction following excessive groundwater extraction from the artesian basin without adequate recharge (Mankey 1963, Ikehara and Phillips 1994), prompted a series of borehole studies of the subsurface geology of the dry lakes (Motts and Carpenter 1968, 1970, Rewis 1993, Sneed and Galloway 2000). Meanwhile, Ponti et al. (1981) mapped the Quaternary surface geology of portions of the Antelope Valley, excluding Edwards AFB. The data resulting from these studies have been re-evaluated and integrated with this research.

Present Research

This report is based on a program of field mapping, remote sensing, subsurface coring, and laboratory investigations conducted on Lake Thompson from 1997 to 2002 within and beyond the confines of Edwards Air Force Base. Field studies proceeded sequentially from Rosamond Dry Lake (Phase I, 1997–1998), through Buckhorn Dry Lake and Mojave Creek (Phase II, 1999–2000), to Rogers Dry Lake (Phase III, 2000–2001), and culminated in a coring program supported by laboratory analysis conducted as part of Phase III from 2001 to 2002.

The field mapping and remote sensing investigations sought to identify the principal geomorphic and lithostratigraphic units and subunits evident at the surface of former Lake Thompson. This information is presented in a large-scale map of the geomorphology and Quaternary geology of that portion of the basin within the confines of Edwards Air Force Base, together with small-scale maps of the entire Lake Thompson drainage basin. Evaluation of the morphostratigraphic units also provides a relative chronology of events for the desiccation of Lake Thompson during late Pleistocene and Holocene time, with emphasis on spatial and temporal relations between sedimentary facies and geomorphology.

The coring program was designed to address the lack of information regarding the temporal devolution of the late Quaternary lake system. The dearth of datable materials in surface and near-surface deposits had hitherto inhibited the development of an absolute chronology. Four cores were retrieved and subjected to careful dating and sedimentological analyses, which, for the first time, reveal information regarding when and how Lake Thompson responded to the fluctuating hydrologies of late Pleistocene and Holocene time. Taken together, the temporal sequence and spatial pattern of events revealed here provide a valuable template for how a relatively large lake has devolved into the complex desiccated system of today.

4 GEOMORPHOLOGY OF LAKE THOMPSON

Methods

Field investigations were designed initially to identify and classify the variety of geomorphic and lithostratigraphic units and subunits evident on the surface of former Lake Thompson. The classification scheme was developed first during Phase I investigations in and around Rosamond Dry Lake, evaluated against vertical color aerial photographs, subjected to further field checks and sediment analyses, revised, and eventually confirmed. As Phase II and Phase III of the project progressed, the scheme was modified and extended as necessary, deleting certain units that had been introduced on theoretical grounds but not found, and introducing new units that had not been present around Rosamond Dry Lake but were observed in the more easterly environments north and east of Rogers Dry Lake. Again, the revised scheme was evaluated against remote sensing imagery, field checks, and sediment analyses.

The classification scheme is presented as Table 1 and also in the legend to the accompanying large-scale map: *Geomorphology and Quaternary Geology within Edwards Air Force Base, California*. Figure 3 presents a summary of this map in terms of predominant surface facies. In approximate stratigraphic sequence from oldest to youngest, Figure 3 depicts (1) pre-Quaternary rocks that reach the surface locally, (2) lacustrine facies that are widely exposed to the south and west of Rosamond Dry Lake, (3) beach–dune ridge complexes around the remnant dry lakes, (4) fluvial facies that are most prominent where significant ephemeral streams enter the lake basin, (5) aeolian facies notably present downwind from Rosamond and Rogers Dry Lakes, and (6) the modern playa facies of these dry lakes. This stratigraphic sequence is frequently interrupted by the interfingering of lacustrine, fluvial, and aeolian facies, reflecting the fluctuating character of the desiccating lake system.

General Observations

Table 1 identifies seven major units for the study area based on the geomorphic expression of the principal landforming lithostratigraphic components in and around former Lake Thompson. These are: Qp (modern playa), Ql (former lake system), Qe (aeolian sand sheet and dunes), Qa (alluvial channels and fans), Qc (talus slopes and colluvial surfaces), B (bedrock uplands), and A (artificial or anthropogenic terrain).

Of these seven major units, three are less significant within the ecological context of the past and present lake basin, namely Qp (modern playa surfaces are

Table 1. Geomorphic and lithostratigraphic units, Lake Thompson.

Unit	Subunit	Geomorphic Unit	Lithostratigraphy	Age
Qp		**Modern Playa**		**Holocene**
	Qpm	Main playa	silt-clay, nearshore sand/salt, deflation, floodable	
	Qpp	Minor pan	silt/clay, minor sand, deflation, floodable	
Ql		**Former Lake System**		**Pleistocene, Holocene**
	Qlp	Exposed lake plain	sand/silt/clay, salt, calcrete, flat bedded	
	Qlpx	Exposed, undissected, flat or gently inclined lake beds		
	Qlpxd	Exposed, dissected, hummocky or irregular lake beds		
	Qlpv	Lake beds veneered with aeolian sand and/or alluvial sand and gravel <2m deep	sand or gravel veneer on above materials	
	Qlpvd	Dissected/degraded lake beds veneered with aeolian sand or alluvial deposits <2m deep		
	Qlb_n	Beach ridge and nearshore ramp ($_n$ refers to ridge in sequence)	gravel/sand, flat to cross-bedded	
	Qlbx	Exposed ridge and ramp		
	Qlbv	Ridge veneered with aeolian sand <2 m deep	aeolian sand veneer, usually cross-bedded	
	Qlbvd	Dissected/degraded ridge with aeolian sand <2 m deep		
	[Qle]	Estuary: now abandoned to active or inactive fluvial washes (Qaa, Qai)	coarser, less-sorted sand and gravel	
	Qll	Back-barrier lagoon	silt/clay, sand lenses	
	Qllv	Back-barrier lagoon veneered with aeolian or alluvial deposits		

Table 1 (cont.). Geomorphic and Lithostratigraphic Units, Lake Thompson.

Unit	Subunit	Geomorphic Unit	Lithostratigraphy	Age
Qe		**Aeolian Sand Sheet and Dune**		**Holocene, Pleistocene**
	Qea	Active sand sheet or dune	medium/fine sand, well sorted	Holocene
	Qeat	Transverse/barchanoid		
	Qeab	Barchan		
	Qeap	Parabolic		
	Qes	Stable sand sheet or dune	medium/fine sand, fines moderately sorted, Fe, Ca	Holocene, Pleistocene
	Qest	Transverse/barchanoid		
	Qesb	Barchan		
	Qesp	Parabolic		
	Qesd	Dissected/degraded sand sheet		
	Qesk	Dune slacks - hollows, blowouts, and ephemeral water courses in sand sheet, reflecting clay or iron pans, underlying lake beds		
Qa		**Alluvial Channels and Fans**		**Holocene, Pleistocene**
	Qaa	Active wash or floodplain (flow infrequent but likely in storms)	gravel/sand, some fines, bedforms	Holocene
	Qai	Abandoned or inactive wash	gravel/sand, fines, aeolian veneer, no bedforms	Holocene
	Qaw	Wetland (little channel flow)	silt/clay, organic mud	Holocene
	Qaf	Alluvial fan (rarely active)	gravel/sand, some boulders, calcrete	Holocene, Pleistocene
	Qafv	Alluvial fan with aeolian veneer		
	Qaf(H)	Holocene alluvial fan	fan overlies lake plain	
	Qaf(P)	Pleistocene alluvial fan	fan descends beneath lake plain and is dissected	
	$Qaf_{1,2,3,n}$	Relative ages of alluvial fan deposits where locally evident		

Table 1 (cont.). Geomorphic and Lithostratigraphic Units, Lake Thompson.

Unit	Subunit	Geomorphic Unit	Lithostratigraphy	Age
Qc		**Talus Slopes and Colluvial Surfaces**		**Holocene**
	Qct	Talus slopes and colluvium (beneath old cliffs and bedrock exposures)	angular/subangular gravel, granitic and conglomeratic cobbles and boulders	
B		**Bedrock Uplands**		**Neogene, Mesozoic**
	Bc	Sedimentary terrain	Buckhorn Fanglomerate	Neogene
			Fiss Fanglomerate	Neogene
			Bissell Formation	Neogene
	Bv	Volcanic terrain	Tuff, breccia, sandstone	Neogene
	Bh	Hypabyssal terrain	Porphyry, felsite, rhyolite quartz latite	Neogene
	Bp	Plutonic terrain	Granite, quartz-monzonite	Mesozoic
	Bpg	Grus terrain		
	Bpgv	Aeolian veneer on grus		
A		**Artificial (Anthropogenic) Terrain**		**Modern**
		(where natural system is visible beneath artificial imprint, the unit is designated A/Qlpx, A/Qaw, etc.)	Stock ponds, dikes, roads, runways, parking lots, enclosures, buildings, etc.	

Notes

(1) All units are subject to aeolian deflation and redeposition. Thus, an aeolian sand or silt veneer is widespread. If the veneer is <2 m deep, the main unit prevails because the veneer is of insufficient thickness to dictate surface topography, although it may have some impact on vegetation. If the veneer is >2 m, it is mapped as Qe because it significantly influences soil development and vegetal response.

(2) Many units, including the Aeolian Sand Sheet and Dune unit, are also subject to occasional fluvial dissection, which causes reworking and redistribution of surface and near-surface materials. Where significant, these are designated Qa.

(3) The [Qle] unit indicates the presence of former small estuaries entering the lake, generally through breaches in the beach ridges. Such areas typically reveal coarser sediment than the adjacent lake plain, but because they later functioned as fluvial washes, they are typically designated as [Qle]/Qaa or [Qle]/Qai.

(4) Deposits of the Exposed Lake Plain (Qlp, Qlpx, Qlpv) and of the Stable Aeolian Sand Sheet or Dune (Qes, Qest, Qesp) are frequently degraded as a result of aeolian deflation without being dissected by fluvial processes. The uppermost beds of each unit have been variably removed, and for the dunes in particular, the indurated ribs of the structural dip slope are exposed. This is particularly pronounced along the eastern margins of Rosamond Dry Lake and farther east. To recognize this, the affix "d" is added to the above units. Degraded environments are mostly hostile to vegetal growth and survival.

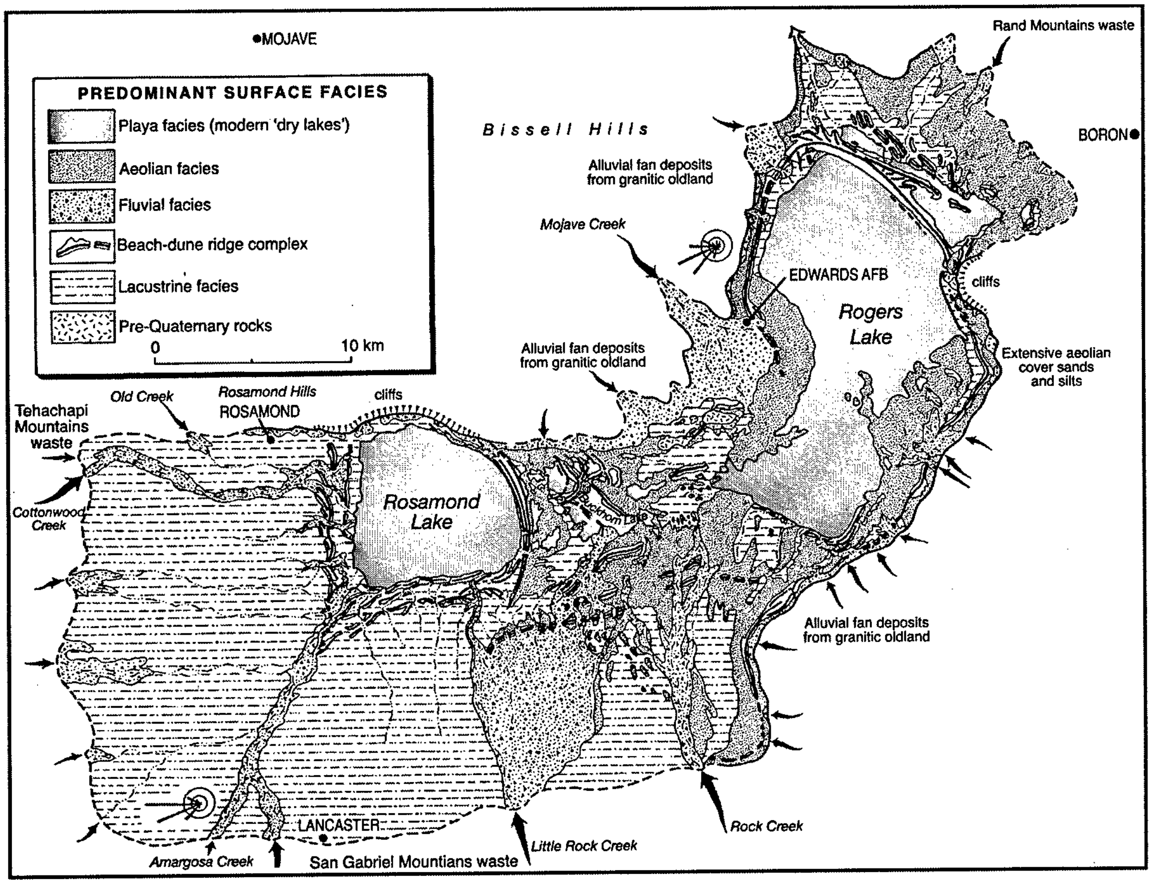


Figure 3. Predominant geomorphic features and lithofacies of Lake Thompson.

largely unvegetated), Qc (talus and colluvium are areally restricted to slopes beneath bedrock exposures and former lake cliffs), and B (exposed bedrock surfaces are mostly marginal to former Lake Thompson although they influence sediment inputs and wind and water flows to other units; small isolated outcrops also occur within the former lake basin). Anthropogenic imprints (A) have locally obliterated the former natural system, notably at Piute Ponds in the southwest angle of Rosamond Dry Lake and above the western shore of Rogers Dry Lake, but where the underlying terrain can be discerned it is recognized as such, for example as A/Qlpx. Elsewhere, anthropogenic imprints from former tillage, grazing, and mining activities have undoubtedly modified the landscape, but the original geomorphic unit is normally evident. However, past grazing activity probably had a role in degrading aeolian sand sheets and dunes (Qe), although the magnitude of this influence remains uncertain.

Among the seven major geomorphic units, 17 subunits are recognized, namely Qpm, Qpp, Qlp, Qlb, [Qle], Qll, Qea, Qes, Qaa, Qai, Qaw, Qaf, Qct, Bc, Bh, Bv, and Bp. These subunits provide the primary basis for geomorphic mapping and ecological identification. Some of the 17 subunits are of limited extent. For example, [Qle] indicates the presence of former small estuaries with coarser sediments than the adjacent lake plain but because these estuaries later functioned as alluvial washes they are designated preferably as Qaa or Qai. Further, some subunits may be locally significant but of limited extent elsewhere. Thus, a large back-barrier lagoon (Qll) lies behind the massive barrier beach at the north end of Rogers Dry Lake, but such lagoons are of small extent around Rosamond Dry Lake, although even here they provide a distinct ecological response. Likewise, dune slacks (Qesk) are important in the dunefields north and northeast of Rogers Dry Lake but insignificant elsewhere.

Certain subunits are amenable to further subdivision of variable importance to the area's ecology. For example, the exposed lake plain (Qlp) varies from exposed undissected flat-lying lake beds (Qlpx), through exposed dissected or hummocky lake beds (Qlpxd), to lake beds veneered with aeolian or alluvial sediment (Qlpv), and any of these units may be further degraded by wind deflation or fluvial dissection (Qlpvd). These distinctions are often reflected in distinct ecological responses. Similarly the aeolian sands (Qe), whether active (Qea) or stable (Qes), are locally arranged into distinctive transverse, barchanoid, and parabolic dune forms. Thus, subdivisions based on dune form are included because of their significance to the evolving geomorphology, although their ecological significance may be negligible.

All units have long been subject to aeolian deflation and subsequent redistribution of aeolian sand and silt. This implies that some surfaces are actively eroding, with resulting stress on vegetation, while others are accreting, with the consequent provision of new habitat. A depth of 2 m has been established as a threshold between aeolian (Qe) and non-aeolian environments: if the sand depth is <2 m, the underlying substrate is assumed to dominate plant ecology; if the sand depth is >2 m, aeolian sediment normally dominates soil development and ecological response. Although useful for field mapping, this 2-m threshold is clearly arbitrary, and some quite small sand piles sometimes produce a distinct vegetal response. To accommodate the presence of aeolian sand <2 m deep on other units, normally on lake plain (Qlp), beach ridge (Qlb), and alluvial fan (Qaf) forms, the affix "v" is used (thus, Qlpv, Qlbv, and Qafv).

Where multiple beach ridges occur, the beach ridge subunit (Qlb) is designated by number (e.g. Qlb_1, Qlb_2, Qlb_n) to distinguish between shorelines of differing ages. This assists in understanding the evolution of the lake system and may help to explain degrees of soil-profile development of relevance to the

ecology. Until this study, there had been no clear indication of the age of these shorelines, but by analogy with similar lakes in the Mojave Desert, it seemed likely that the more prominent beach ridges just above Rosamond and Rogers Dry Lakes were late Pleistocene to early Holocene in age (approximately 22–9 ka). This issue was revisited following the discovery of datable materials in the beach ridges and correlative lake basin deposits (Chapter 5).

The geomorphic units defined in Table 1 provide a basis for the mapping of former Lake Thompson that also demonstrate the ecological relationships of the overlying vegetation and associated soils. The mapping units and subunits are based on sound geomorphic principles in that they represent an identifiable hierarchy of units, capable of subdivision, that has both generic and genetic significance. The system has been carefully developed and repeatedly tested against field observations during the mapping program and has further implications for surface and near-surface hydrology and the identification of potential flood hazards.

Geomorphic and Lithostratigraphic Units

The Modern Playa (Qp)

Modern playas and their associated deposits are divided simply into two units: the main playas of Rosamond and Rogers Dry Lakes (Qpm), and the lesser playas around Buckhorn Dry Lake and the minor pans on the former lake plain beyond the main playas (Qpp). The limits of both units are defined in terms of recent lacustrine deposits in essentially flat areas devoid of visible vegetation. For Rosamond Dry Lake, this corresponds with the area flooded during the relatively wet winter of 1992, as shown by recent inundation on color aerial photographs of April 26, 1992. For Rogers Dry Lake the 1992 inundation did not cover the entire lake bed, and for the southern part of the lake, it is possible to distinguish between areas that in April 1992 were not flooded (Qpm_1), were briefly flooded during winter (Qpm_2), and were affected by more prolonged flooding during winter and spring (Qpm_3). This hydrological distinction was not possible for northern Rogers Dry Lake, where aerial imagery was obtained on August 8, 1992, following complete desiccation of the temporary lake, and thus is not incorporated in the final map.

Playa deposits are textural silts and clays, with 40–70% less than 1 μm in size, with a veneer of medium to fine sand subject to reworking by wind. As it dries, the surface ranges from smooth to puffy in appearance, with clay curls frequently present. There is little sign of life, visible organic carbon is negligible, and vegetation is absent.

Minor pans (Qpp) occur most numerously east of Rosamond Dry Lake and north and east of Rogers Dry Lake. East of Rosamond, beyond the crests of the first transverse dunes but interspersed with other dunes and sand sheets, minor pans extend eastward toward the series of larger pans around Buckhorn Dry Lake. In this area the pans lie at or only slightly above the elevation of the main playa and normally represent a thin veneer of recent playa sediment lying on the former lake plain. Certainly around the two small hills of conglomerate, herein named the Buckhorn Conglomerate, the former lake plain emerges to grade upward into beach deposits. Elsewhere, small pans exist behind beach ridges along the south and west shores of Rosamond Dry Lake and the east shore of Rogers Dry Lake, some of them inherited from back-barrier lagoons (Qll) related to higher lake levels. A more extensive series of pans occurs north of the barrier beach at the north end of Rogers Dry Lake. The largest of these may also be designated back-barrier lagoons because, although they originated on the larger floor of Lake Thompson, they were subsequently isolated from the main playa by barrier-beach accretion.

The Former Lake System (Ql)

Two geomorphic units dominate the former system of Lake Thompson: its elevated lake plain (Qlp) and the several beach ridges (Qlb) related to former stillstands during episodic oscillations of the lake. Two lesser units related to former stream estuaries ([Qle]) and back-barrier lagoons (Qll) are locally noteworthy.

At its maximum Lake Thompson covered about 950 km^2 to an elevation of 710 m above sea level, extending from south and west of Rosamond to north of Rogers Dry Lake. From time to time during the late Pleistocene, this lake may have spilled northwest into Fremont Valley through a shallow strait between Castle Butte and Desert Butte, but the precise timing and persistence of this connection must await further research in Koehn Dry Lake, the sediment sump within Fremont Valley. Owing to subsequent degradation, shorelines related to Lake Thompson's maximum highstand are often poorly defined, but at some relatively high stage the cliff along the north shore of Rosamond Dry Lake was shaped by wave action.

Although the broader region beyond the lake has experienced episodic tectonic deformation and faulting during late Cenozoic time, related to epeirogenic uplift of the western Mojave Desert and movement on the bordering San Andreas and Garlock fault systems, there is no clear morphometric evidence for deformation of Lake Thompson's more recent shorelines. Such deformation cannot be wholly discounted, particularly in view of recent faulting and

earthquake activity in the western Mojave Desert associated with the Walker Lane seismic zone. It is also likely that differential warping of the Antelope Valley, Fremont Valley, and intervening Bissell Hills affected both the episodic connection between Lake Thompson and Lake Koehn and the drainage systems contributing to these lakes, including Mojave Creek.

The lake plain (Qlp) presents a monotonous landscape of grayish green silts, either exposed (Qlpx) or thinly veneered with alluvium and aeolian sand (Qlpv) deposited following withdrawal from the maximum highstand. These are in turn sometimes dissected (Qlpxd, Qlpvd) by occasional surface flows from adjacent uplands and/or degraded by wind deflation and erosion. The lake plain is most extensive south and west of Rosamond Dry Lake, although its precise surface dimensions here have been obliterated by subsequent deflation and fluvial deposition. To the north, it was confined by the mostly granitic Rosamond and Bissell Hills and farther east by the granitic uplands rising above Rogers Dry Lake. The lake plain also appears beneath aeolian sands and recent alluvial, lagoonal, and pan sediment both north and south of Rogers Dry Lake.

At lower elevations towards the present dry lakes, the monotony of the lake plain is broken by several beach ridges (Qlb). Around Rosamond Dry Lake the most prominent of these is the beach–ridge complex that extends along most of the east shore before disappearing beneath aeolian and alluvial deposits towards Rosamond Boulevard in the north or behind lake plain and dune deposits towards the south. Where broadly exposed, this complex comprises three major beach ridges, the upper two with multiple swash ridges, but it is the lowest ridge that is most broadly developed. The latter extends for 4 km along the eastern shore, the slight variation in its crest elevation, between 699 and 701 m, being attributable to normal wave processes. At least two suites of beach ridges occur along the south and west shores of Rosamond Dry Lake, where their continuity is often broken by distributaries of past and present drainage. Accordingly these beach ridges adopt forms common to many estuarine situations, curving into and then disappearing inside the former estuaries. Former estuarine deposits ([Qle]) and back-barrier lagoons (Qll), often present as small pans (Qpp) in the modern landscape, occur in association with the beach ridges.

Modest beach ridges also characterize the downwind (eastward) margins of the larger playas in and around Buckhorn Dry Lake. These are commonly mantled with aeolian sands in various stages of degradation. Farther south, from Buckhorn Dry Lake to the southern Edwards AFB perimeter, many sand dunes are aligned from east to west and are probably superposed on concealed beach ridges indicative of stillstands in Lake Thompson's evolution but subsequently dissected by streamflow from the San Gabriel Mountains.

The most massive beach ridge of the former lake is the large barrier complex toward the north end of Rogers Dry Lake. This barrier extends nearly 10 km from near the main lake's northernmost margin southeastward to granite hills along the eastern shore. It is widest and highest at its northwest end, where its 500-m width is augmented by aeolian dunes to an elevation of 710 m, but less than 100 m wide and only 695 m high at its southeastern end. The several ridges within this barrier complex suggest several wave-building phases within a net eastward nearshore current system. At its northwest end the barrier curves southward across the lake's former spillway to merge with a more modest barrier, 698–702 m above sea level and rarely more than 100 m wide, that extends southward for 10 km into the main operating areas of Edwards AFB. Except at its northern end this latter barrier has been largely destroyed by excavation and subsequent construction such that its original structure must remain largely conjectural. There are no prominent barrier beaches along the east shore of Rogers Dry Lake, owing largely to subsequent fluvial dissection and aeolian deposition, but Lake Thompson's former eastern shore is locally discernible beneath the aeolian mantle at the interface between veneered lake plain and alluvial fan deposits.

Beyond the barrier beach–dune complex towards the northern end of Rogers Dry Lake lie several smaller beach ridges, much dissected and mostly veneered with aeolian sand. The orientation of these ridges suggests a pattern of episodic regression from the maximum stage(s) at which the lake spilled northwest to Fremont Valley. Stillstands during regressional phases permitted the development of oblique subaqueous bars in the prevailing wind and current regime, and these also became mantled later with aeolian sand. The variety of beach and aeolian forms in this area generates a corresponding variety of small ecosystems.

As noted above, of the remaining units associated with the former lake system, abandoned estuaries ([Qle]) at the mouths of streams entering the lake are locally prominent around the south and west margins of Rosamond Dry Lake, while small back-barrier lagoons (Qll) lie behind nearby beach ridges. Such lagoons are more prominent north of the barrier beach–dune complex at Rogers' north end where they represent components of the former lake floor isolated by barrier construction and now subject to somewhat different sedimentary regimes.

The ages of the lake–plain and beach–ridge deposits of former Lake Thompson are discussed in Chapter 5. A notable feature of surface investigations was the paucity of organic debris that might be used to provide a radiometric chronology of lake fluctuations. In comparable situations throughout the Mojave Desert and Owens River system, beach ridges and nearby estuarine deposits sometimes contain gastropods and pelecypods, notably *Anodonta californiensis*, indicative of freshwater and brackish water life, which, for the past 40,000 years,

may be dated by radiocarbon methods. No such organisms have yet been found in surface exposures around the lake basin, most likely because such life-forms as did exist have been destroyed by subsequent subaerial weathering.

Aeolian Sand Sheet and Dune (Qe)

Aeolian features associated with former Lake Thompson are broadly divided into those that are active (Qea) and those that are stable (Qes) under present conditions. Each subunit is further defined in terms of dune shape, namely transverse (t), barchan (b), and parabolic (p) dunes. In reality, despite the continuing importance of wind action across the basin, there are very few truly active dunes (Qea) and few true barchans within the mapped area. This is because dune construction requires not only effective winds above the threshold velocity for sand entrainment but also ample supplies of sand. Such supplies were presumably available in the more distant past as a result of seasonal, even perennial, fluvial transport from the lake's vast watershed. With the drier conditions and ephemeral flows of the recent past, however, relatively little dune-forming sand has been reaching the lake basin, and that already present has been lithified or removed downwind.

Active dunes (Qea), specifically those with active slip faces generated by downwind transport across loose sand, are largely confined to the first dune ridge around the southeast angle of Rosamond Dry Lake, including one dune opposite a breach in the eastern barrier beach complex, and to isolated dunes within the Buckhorn area between Rosamond and Rogers Dry Lakes. Even here, the upwind portions of the dunes are indurated and degraded, but sufficient loose sand moves across the crest to generate unstable slip faces. Elsewhere, strong winds, especially during the spring months, readily move loose material across the playa and its environs, generating ripples of coarse sand and piling sand against shrubs and other obstacles, but there is insufficient material to build dunes or form active sand sheets. Human interference, first through grazing animals and later through military activity, has played a variable role in destabilizing old sand dunes and generating renewed movement, but this is site specific and not readily measured.

Most sand sheets and dunes in and around former Lake Thompson are essentially stable (Qes) but subject to varying degrees of degradation as a result of continuing deflation and abrasion (Qesd). Such is the nature of dune deposition that the upwind portions of stable dunes are often degraded to their indurated slip faces, which protrude as ribs dipping 10° to 32° downwind and away from the dune axis. Degraded dunes have commonly lost their soil profiles and provide harsh alkaline habitats that are hostile to vegetation. Their indurated

nature promotes surface runoff during rare rainfall events, such that small rills and some larger gullies locally occur. These effects are exemplified in the aeolian corridor extending downwind from Rosamond Dry Lake, through the Buckhorn area, to the southwest and southeast shores of Rogers Dry Lake, and again north from Rogers Dry Lake.

The most extensive stable sand sheets and dunes lie downwind from the barrier-beach complexes at the eastern and northern ends of Rosamond and Rogers Dry Lakes. Here, what were initially transverse dunes forming on lake backshores have commonly been shaped into lobate forms as sand supplies diminished. Lobate forms are intermediate between transverse and parabolic dunes, and with sufficient wind-forcing, true parabolic dunes occur, sometimes harboring small pans inside their upwind arms. Clusters of parabolic dunes are most common northeast of Rogers Dry Lake on sloping terrain south of the old railroad grade, where wind fetch across the lake is maximized. A further extensive sand sheet, or aeolian veneer, characterizes the alluvial fans and granitic hills rising toward Haystack Butte beyond the eastern shores of Rogers Dry Lake. This broad ramp, rising to more than 1000 m, or 300 m above the lake floor, is a natural trap for aeolian sand and silt transported from the lake bed, past and present.

Dune slacks (Qesk) are a common feature of the sand sheet northeast of Rogers Dry Lake. These are depositional hollows, eroded blowouts, and ephemeral water courses in the undulating dune sheet that maintain relatively high water tables during and after the rainy season. Such high water tables reflect in part the presence of clay pans and iron pans within the sand sheet, and subjacent lake beds at shallow depth beneath aeolian sand. Dune slacks appear to impact local ecology by maintaining higher soil-water content for much of the year.

The sand sheets and dune fields within the lake basin originated during and after the desiccation of Lake Thompson and are therefore no older than the terminal Pleistocene (see Chapter 5). Stratigraphic relations also indicate that dune formation occurred in several phases before, during, and after the shaping of Rosamond, Buckhorn, and Rogers Dry Lakes as discrete entities. However, because the winds that formed these dunes continued as sand supplies diminished, massive erosion and downwind transport of surviving sand masses has continued to occur throughout the Holocene. Net aeolian erosion, rather than deposition, now prevails within the basin.

No surficial evidence has been found to provide a more precise chronology for Holocene dune formation. By their nature, dunes and sand sheets are commonly devoid of materials suitable for radiocarbon dating. Even where

organic material has survived wind abrasion and weathering, it is contaminated by or encrusted in secondary carbonates, as rhizoconcretions and pedogenic calcrete, and thus does not provide realistic radiocarbon ages. Luminescence and other surface-exposure techniques lack adequate resolution for the presumed age range of these deposits.

Alluvial Channels and Fans (Qa)

Four alluvial subunits are recognized in and around former Lake Thompson: active washes (Qaa), abandoned or inactive washes (Qai), wetlands (Qaw), and alluvial fans (Qaf). The alluvial fans are subdivided along the north shore of Rosamond Dry Lake between those that overlie lake plain deposits and have been active during the Holocene (H) and those that are clearly relict features of probable Pleistocene age (P). Further, those fans descending to the south and east shores of Rogers Dry Lake may be distinguished in terms of relative age by the intensity of the varnish coating on their constituent surface gravels into Qaf_1 (the oldest), Qaf_2, and Qaf_3 (the youngest fan components above active washes). Whereas these fan-age distinctions are ecologically significant in terms of plant succession, they cannot be applied basin-wide and are not included in the map.

The term "active" requires definition in a desert environment where rainfall is sparse and streamflow rare. The term applies to those channels, floodplains, and fans where evidence for recent streamflow survives in the form of alluvial bedforms such as ripples and dunes, normally indicative of the lower flow regime, or where other forms of fluvial erosion and deposition such as point bars and cut banks occur. Such streamflows may occur during winter rainstorms or summer thunderstorms. Some are the product of flows during the 1999-2000 winter, some relate to flows a few winters past (for example, to rainfall events during 1997-98 and 1998-99), and some are relicts of earlier flow events not yet erased by aeolian activity. Some are the result of groundwater flows emerging at the surface and flowing for short distances before disappearing down swallets in the channel. In short, the implication of the term "active" is that streamflow is probable at some time or other over a period of a few years and that during high rainfall events, flooding is likely. Whereas the precise probabilities have yet to be defined, it is likely that active washes see significant streamflow at least once every 10 years. Beyond that time, geomorphic evidence for modest streamflows is usually erased by wind action, although the record of larger flows such as those associated with the 1982-83 El Niño event persist along the southwest margins of the lake basin.

Whereas an "active wash" (Qaa) may yield no flowing water for most of the year, sometimes for several years, the term "inactive wash" (Qai) is reserved for

those channels that show no evidence whatsoever of recent streamflow and yet retain channel form. Relatively few washes are truly inactive, and many of those that do occur may be explained, for example on the Mojave Creek fan delta, by artificial drainage diversions.

Active washes (Qaa) are most prominent along the south side of Rosamond Dry Lake, where drainage from the San Gabriel Mountains via Amargosa and Little Rock Creeks forms a system of distributaries across the former lake plain. Channels are locally incised 1–2 m into lacustrine deposits and overlying aeolian sands, and beach ridges are breached at frequent intervals. At least three such channels reach the present south shore of the lake, and a complex of distributaries related to Amargosa Creek occurs in and around the Piute Ponds at the southwest angle. Cottonwood Creek and two adjacent channels from the Tehachapi Mountains feed streamflow towards the western shore of the lake, where poldering again locally interrupts the flow. Along the north side, several occasionally active washes draining from the adjacent granite uplands and old fanglomerate terrain [Qaf (P)] have built small alluvial fans [Qaf(H)] over former lake beds. East of the Rosamond barrier-beach complex along the east side, occasional flows from the north are diverted towards the downwind dune field and related pans in and around Buckhorn Dry Lake. During incident rains on the barrier complex and adjacent degraded dune front, surface waters flow west to Rosamond Dry Lake over relatively impermeable lake beds and indurated aeolian sands.

Farther east, distributaries of Rock Creek and Big Rock Creek descend from the San Gabriel Mountains onto the veneered lake plain between the Buckhorn area and the south end of Rogers Dry Lake, frequently disappearing and re-appearing among the lake beds and aeolian cover. Farther east, winter rains and summer thunderstorms over the hills generate ephemerally active channels that descend to the eastern shores of Rogers Dry Lake across prominent alluvial fans, and the same is true for ephemeral streams reaching the lagoons along Rogers' north shore.

Mojave Creek is the most significant ephemeral stream entering Rogers Dry Lake, and in doing so it follows a well-developed alluvial valley between low bedrock uplands before debouching onto the military infrastructure near the intersection of Rosamond and Lancaster Boulevards. Early recognition of the occasional flood hazard posed by this creek should have directed development projects away from its fan delta. During the major El Niño event of 1982-83, a significant portion of this fan delta and base runways were temporarily inundated by Mojave Creek floodwaters. The geomorphic map shows the extent of the potentially active and inactive washes associated with this creek, although

because local gradients are so low, it would seem relatively easy to engineer a preferred future route for creek floodwaters.

Over the longer term, Mojave Creek poses interesting questions because, from its headwaters in the front range of the Tehachapi Mountains, it flows across nearly flat terrain southeast of Mojave into the Bissell Hills before descending more steeply into Rogers Dry Lake. The neighboring headwaters of Cache Creek follow a similar route before turning through 90° to descend into Koehn Dry Lake. These patterns suggest uplift of the Bissell Hills relative to Fremont Valley and possible changes in the hydrological inputs to both Lake Thompson and Lake Koehn during the later Quaternary. Such changes, including diversion of one or both creeks, may have contributed to the fluctuating water volume of Lake Thompson.

Wetlands (Qaw) dominate the southwest angle of Rosamond Dry Lake. Here, the Amargosa Creek drainage, augmented by urban runoff and sewage waters from communities such as Lancaster and Quartz Hill to the southwest, has been grossly modified by poldering such that it is difficult to reconstruct former drainage patterns from surviving field evidence. It is likely that some natural wetlands existed here prior to impoldering, as this is where Rosamond Dry Lake comes nearest to the San Gabriel Mountains and gradients are least, but human activity has greatly increased the wetland area. Elsewhere, true wetlands characterized by freshwater and brackish water marsh plants are rare, although dune slacks beyond the north end of Rogers Dry Lake locally favor seasonally moist habitats during rainy winters.

Owing to the lack of perennial streamflow and thus more efficient sediment transport, alluvial fans (Qaf) occur across the broad periphery of former Lake Thompson. Beyond the lake's southern and western margins, low-gradient fans merge imperceptibly with the former lake plain, and surface distributaries are mapped preferably as active (Qaa) and inactive (Qai) washes between exposed (Qlpx) and veneered (Qlpv) lake beds. Steeper fans are more prominent along the lake's northern margins, where they are formed from waste derived from plutonic and minor intrusive rocks exposed in the Rosamond and Bissell Hills, and it is here that a distinction can be made between older (Pleistocene) fans truncated by the lake's shoreline and younger (Holocene) fans that descend across that shoreline towards the present dry lakes. In the hills above the lake margin, however, gradation between shallow alluvial deposits and weathered bedrock implies an arbitrary distinction between Qaf and B mapping units. The most prominent fans are those that descend from the uplands east and southeast of Rogers Dry Lake. These are widely veneered with aeolian sand and silt east of the lake, but to the southeast the boundary between upland fans and Lake Thompson's shoreline is more marked.

Talus Slopes and Colluvial Surfaces (Qc)

Talus slopes formed of gravity-fed colluvium (Qct) occur beneath the former lake cliffs along the north shore of Rosamond Dry Lake, a narrow strip of terrain broken by alluvial washes and fans. This category is included because talus is essentially a product of gravitational mass wasting without the intervention of flowing water or other transporting processes. The category covers only a small area, but, whereas it could be combined with the preceding Qa category in terms of ecological response, its constituent materials are essentially coarse and angular.

Bedrock Uplands (B)

Pre-Quaternary bedrock outcrops above the north shore of former Lake Thompson north of Rosamond Boulevard and above the east shore east of Rogers Dry Lake. The bedrock is composed predominantly of Mesozoic plutonic rocks (Bp), mostly granite and quartz-monzonite, interspersed with hypabyssal dikes of porphyry, felsite, and rhyolite (Bh), and with volcanic tuff, tuff-breccia, and sandstone (Bv) related to Neogene (Miocene) volcanism. Red Hill at the northwest corner of Rosamond Dry Lake is the most prominent of the lakeside outcrops and would have formed a significant feature at the former lakeshore. Various volcanic and hypabyssal rocks also form prominent buttes along the watershed periphery, notably Haystack Butte east of Rogers Dry Lake and Castle Butte and Desert Butte near the former spillway to the Fremont Valley. Two small outcrops of quartz monzonite straddling Lancaster Boulevard near South Base formed low islands linked by a sand and gravel tombolo during Lake Thompson's intermediate stillstands. Plutonic rocks, and particularly the grus derived therefrom, provide the source material for most of the coarser lacustrine sediment found within the lake basin, most notably reflected in the composition of the barrier-beach complexes at the downwind margins of Rosamond and Rogers Dry Lakes.

Sedimentary bedrock is of limited extent and significance. The Neogene Bissell Formation occupies a small area in the Bissell Hills on Lake Thompson's northern watershed margin, where it is represented by unfossiliferous lacustrine limestone and claystone and by fluviatile sandstone and conglomerate. It is presumably a remnant of a former lake and alluvial system of uncertain dimensions associated with changing tectonic and climatic conditions prior to the formation of Lake Thompson. The Neogene Fiss Fanglomerate, a brown volcanic fanglomerate, occurs along the south flanks of the Rosamond Hills along the former lake's northwest margin, where it provided coarse clastic materials to the lake shore.

Two small hills of granitic fanglomerate rise prominently from beneath lacustrine and aeolian deposits amid the Buckhorn complex of dry lakes. These hills rose above Lake Thompson's intermediate stillstands, and perhaps above the maximum highstand, forming islands subsequently linked by a sand and gravel tombolo. Individual granitic boulders up to 1 m in diameter show evidence of sculpturing by wave action. This fanglomerate is herein termed the Buckhorn Fanglomerate to distinguish it from the Fiss Fanglomerate with its mostly volcanic clasts to the northwest. The former is an anomalous formation of uncertain age, presumably derived from the denudation of exposed plutonic uplands to the north and isolated by the subsequent erosion of a more widespread deposit.

Artificial (Anthropogenic) Terrain (A)

Despite archaeological evidence for the occasional, probably seasonal, use of the lake and its resources by prehistoric peoples, it is unlikely that these activities had much impact on the geomorphology of the Lake Thompson area, although their role in promoting ecological change needs careful evaluation. In contrast, much of the former lake and its immediate surrounds have been significantly influenced by historic human activity: by mining of igneous and sedimentary rocks and lacustrine deposits; by tillage, grazing, poldering, homesteading, and the construction of wells and irrigation canals throughout the lake's sedimentary basin; and by railroad construction. Although these activities have now ceased within the confines of Edwards AFB, their legacy lingers on in the physical landscape and its ecology. Furthermore, these past activities raise questions as to how important they were in influencing the present distribution of landforms and lithostratigraphic units around the lake. Grazing in particular may have accelerated the degradation of aeolian dune fields by destabilizing the vegetation cover.

Recent operations within the confines of Edwards AFB, notably construction of roads, runways, parking areas, and various buildings, have generated major changes in and around the former lake floor, including the destruction of former shoreline sequences along the western margins of Rogers Dry Lake and the widespread disruption of lacustrine, aeolian, and alluvial deposits and associated landforms. These changes pose problems for the interpretation of former natural features beneath built areas. In addition, the provision of firing and bombing ranges for military purposes and of recreational facilities for base employees, and the off-road use of vehicles, have caused widespread but variable environmental damage, most notably around the margins of Rogers Dry Lake.

Where artificial features dominate the landscape, for example at Piute Ponds southwest of Rosamond Dry Lake and around the military/aerospace complex

west of Rogers Dry Lake, the A unit is widely used. Where such features only thinly conceal the natural system or where that system can be reasonably reconstructed, the A designation is used in conjunction with the inferred natural unit, for example A/Qlpx in localities south and west of Rosamond Dry Lake.

5 LAKE STRATIGRAPHY AND CHRONOLOGY

The floor of former Lake Thompson has been probed for various purposes over the past 120 years. These probes have included numerous water wells, aquifer investigations, some hard mineral studies, and a few deep exploratory searches for oil and gas. Extant well logs and borehole data have been investigated as part of this study, and the more reliable information has been incorporated into a preliminary reconstruction of lake stratigraphy depicted in Figure 4. Without exception, however, these earlier records are silent on the age of Lake Thompson's various stratigraphic units. Until the aquifer surveys conducted by the United States Geological Survey in the 1990s, these records were also commonly vague on the precise character of subsurface sedimentation. For these reasons, a modest program of subsurface coring was initiated within the limits of available resources, and the resulting data were subjected to dating and clay-mineral analyses as appropriate. The results contained here are the first indications of the age and character of the deep lake and its subsequent desiccation during late Pleistocene and Holocene times.

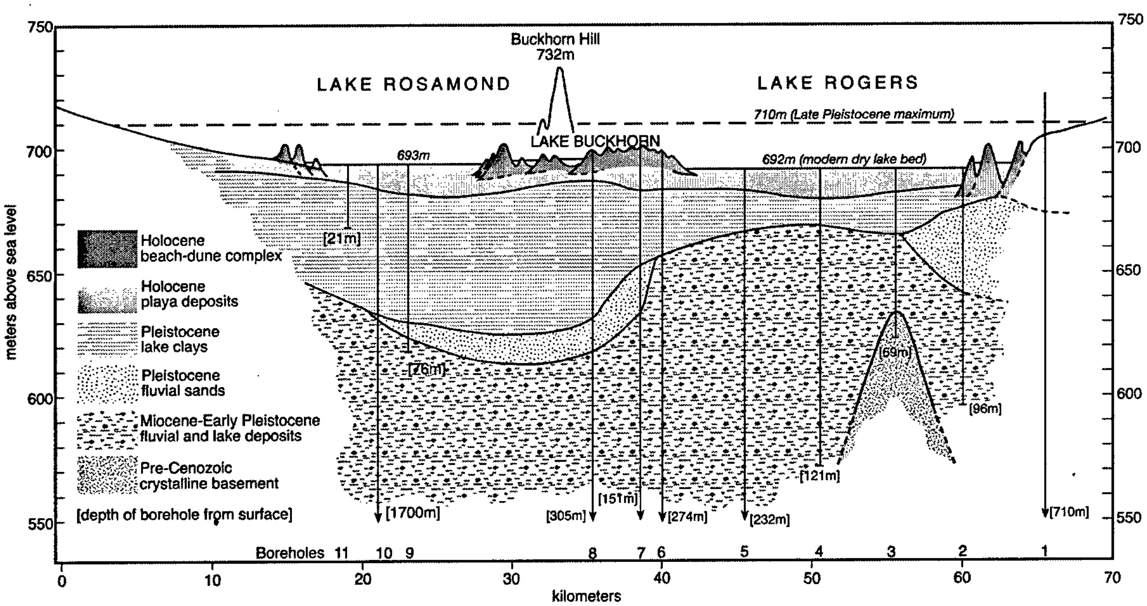


Figure 4. Profile across Lake Thompson based on prior investigations (Dibblee 1963, Motts and Carpenter 1970, and Rewis 1993).

Lake Reconstruction from Past Records

Figure 4 reflects a transect across Lake Thompson from the northeast margin of Rogers Lake to the southwest margin of Rosamond Lake. The reconstruction is based on an evaluation of selected borehole data along this transect. Borehole #1 was the USGS Four Corners No. 2 core 8 km west of Boron, drilled to an eventual depth of 710 m between 1955 and 1957 (Dibblee 1960). Borehole #10 was the C.W. Colgrove-Hughes exploratory oil and gas well drilled to a depth of 1700 m near the southern margin of Rosamond Lake in 1952 (Dibblee 1963). Boreholes #9 and #11 were Ros-2 and Ros-3 obtained by Motts and Carpenter (1970). The remaining boreholes were obtained as part of a USGS drilling program concerned with groundwater withdrawal and surface deformation, reported by Rewis (1993).

Although the objectives and descriptive parameters of these coring programs varied, they reveal the fundamental nature of the former lake system and its associated materials beneath the modern Rosamond–Buckhorn–Rogers playa series. Pre-Cenozoic crystalline basement appears at shallow depth in only one core, 58 m beneath the surface in Borehole #3, where it effectively separates the small North Muroc groundwater basin from the large Lancaster groundwater basin (Rewis 1993). Even the deep Borehole #10 did not reach crystalline bedrock at a depth of 1700 m, or 1007 m below sea level. This testifies to the great depth and irregular floor of the sedimentary basin beneath the Antelope Valley, which geophysical evidence suggests may descend to 1500 m below sea level (Sneed and Galloway 2000).

Most deep boreholes (#2 through #10) penetrate a mix of fluvial and lacustrine sediments at depths between 23 and 70 m beneath the surface but, except in Borehole #3, do not reach crystalline bedrock. The age of these deposits is uncertain, but they appear terrigenous and probably include members of the Tropico Group, a mix of fluvial, lacustrine, pyroclastic, and volcanic rocks of Miocene age that outcrop in the Bissell Hills and elsewhere around the margins of former Lake Thompson (Dibblee 1960, 1963). Although the details of the Tropico Group need not concern us here, the interfingering of lacustrine carbonates with fluvial conglomerates and sandstones within the group indicates the episodic occurrence of lakes and stream floods in the region as early as the Miocene. Similar conditions probably continued through Pliocene and earlier Pleistocene time.

Beneath Rosamond and Buckhorn Dry Lakes, Boreholes #7 through #10 penetrate fine to coarse sand interbedded with sandy clay of probably Pleistocene age. In the absence of conglomeratic facies, the yellowish brown to yellowish green color of these deposits suggests alternating oxidizing and anoxic conditions

under depositional conditions more tranquil than before, perhaps the prelude to the subsequent development of a deep lake.

The most significant feature of most boreholes is the predominance of cohesive clays, silty clays, and sandy silts extending from about 10 m to nearly 70 m below the surface. As described by Motts and Carpenter (1970) and Rewis (1993), these clays are typically yellowish brown to dark greenish gray and occasionally blue. They are interpreted in Figure 4 as lake clays and must surely represent the accumulation of fine clastic material from suspension in a relatively deep lake, former Lake Thompson. Assuming a former highstand of 710 m above sea level, this lake was 80–85 m deep beneath the southeast corner of Rosamond Lake and the Buckhorn corridor. It was shallower farther northeast beneath Rogers Lake, probably because of bedrock constraints.

The deep lake beds are in turn overlain by mostly fine sand with silt and clay interbeds typical of the modern playas, by medium to coarse sand and fine gravel of the beach ridges, and by medium to fine sands of the aeolian dunes. In general terms, these deposits reflect the fluctuating desiccation of Lake Thompson during late Pleistocene and Holocene time.

Methods

The foregoing evidence supports the existence of a former deep lake but is silent regarding its precise chronology and desiccation. Consequently a coring program was conducted to explore, characterize, and hopefully date the later stages of Lake Thompson's existence. Drilling operations were conducted between November 14 and 20, 2001, by Antony Orme, using A and W Drill Rentals, La Habra, California. The necessary permits were obtained by Thomas Mull, Tybrin Corporation, Environmental Management Directorate, Edwards AFB. Four cores were retrieved along a transect from the west shore of Rosamond Lake, through the Buckhorn corridor, to the northeast shore of Rogers Lake, as follows:

- **RW1**: Beach ridge west of Rosamond Dry Lake, at the intersection of Division Street with Avenue A, to a depth of 12 m (~39.5 ft) beneath the surface (T8N, R12W, Section 2, NW quarter, NW corner). Drilling operations at this site became problematic owing to the rapid loss of drilling mud into lateral voids in the subsurface below 5 m. Rather than case the borehole, operations were transferred to RW2, 1.6 km to the north.
- **RW2**: Beach ridge west of Rosamond Dry Lake, again immediately east of Division Street, 1.6 km north of RW1, to a depth of 21 m (~69 ft) beneath the surface (T9N, R12W, Section 35, NW quarter, NW corner).

- **TL1**: Small pan near the junction of Branch Memorial Park Road with Lancaster Boulevard, in the Buckhorn corridor between Rosamond and Rogers Dry Lakes, to a depth of 34 m (~112 ft) beneath the surface (T9N, R10W, Section 34, SE quarter).
- **RE1**: Beach ridge at northeast margin of Rogers Dry Lake, immediately south of the gravel Lakeshore Drive, to a depth of 20 m (~65 ft) beneath the surface (T10N, R9W, Section 11, W center).

Cores approximately 3.8 cm (1.5 in.) in diameter were retrieved in 0.6-m (2-ft) increments using a split-spoon sampler, 5 cm (2 in.) in outside diameter. The general nature of the core material, any loss on retrieval, and the depth of each segment were recorded and logged on site. The cores were then boxed and transported to the laboratory.

The cores were subsequently split lengthwise and the opposing open faces inspected visually for texture, color, organic material, and carbonate content. Texture is a measure of the nature and range of conditions in the sedimentary environment. Color may be an indicator of mineral content and thereby of aerobic or anaerobic conditions. Organic material may also reflect the sedimentary environment but, more importantly, may offer material suitable for radiocarbon dating. Carbonate content is a reflection of both depositional and post-depositional conditions. These data were recorded in extended log descriptions and are discussed below. Sediment samples were extracted for clay-mineral analysis from one side of the open-face core of RW2 and TL1 at intervals from 0.3 to 2.0 m, depending on the character of the deposit.

The search for organic materials suitable for radiometric dating was a primary objective of the visual inspection. Many Pleistocene and Holocene lake beds contain abundant macrofossils (shells, wood, etc.), as well as microfossils (ostracodes, diatoms, pollen, etc.). Unfortunately, beyond the rootlets of modern plants, very little such material was apparent in the Lake Thompson cores, nor was any visible shell debris encountered. The absence of shell material was not surprising in view of its absence from surface exposures, but it implied that the former lake environment was either hostile to molluscan life or, more likely, that such life as did exist had been erased by subsequent weathering and the carbonates derived therefrom reconstituted as pedogenic calcrete. To further this quest, selected sediment samples were floated in water to see if microscopic carbon might disaggregate from the matrix. This process revealed some apparent charcoal flecks and suggested that the accelerator mass spectrometry (AMS) technique might yield radiocarbon ages.

To test the suitability of vaguely organic debris for radiometric dating, four initial samples were forwarded to Beta Analytic, Inc, Miami, Florida, specialists

in radiocarbon dating. After pretreatment and acid washing, these samples were found unsuitable for radiometric dating, but two samples from the beach ridge west of Rosamond Lake (RW2@20 and RW2@39) were suitable for AMS dating and subsequently yielded interesting ages in the 20,000-year BP range. These are the first definitive ages recorded for former Lake Thompson. Attention then turned to seeking AMS ages from bulk samples, requiring careful pretreatment and repeated acid washes. Accordingly, several 15-cm-long bulk samples were forwarded for AMS analysis, and because it was uncertain at what depth the radiocarbon content would exceed the useful range of the method (~40,000 years BP), these samples were processed stepwise. The majority of these samples yielded interesting radiocarbon ages, reported in Table 2 and discussed below.

Chronostratigraphy

Tables 3–6 present the essential sedimentological properties and stratigraphic sequence of materials from the four cores, augmented for RW2 and TL1 by a series of AMS ages. It was deemed preferable to direct available resources into establishing a more detailed chronology for two different core environments, RW2 towards the western margin of Lake Thompson and TL1 near the deepest part of the former lake. Consequently cores RW1 and RE1 are not supported by radiocarbon ages but have been preserved for possible future dating.

Rosamond West Beach Ridge (RW1 and RW2)

The two cores retrieved from above the west shore of Rosamond Dry Lake clearly reveal the relationship between the former deep Lake Thompson and the overlying beach ridges formed as a result of the lake's reappearance, or at least transgression from a lower level. The stratigraphy represented in Tables 3 and 4 is discussed from the surface down.

As shown on Figure 3, the principal beach ridges above the west shore of Rosamond Dry Lake form a discontinuous north–south series approximately 1–1.5 km west of, and rising 8 m above, the present playa margin. Ridge segments are curved in response to estuarine conditions at the mouths of former small creeks, of which the most prominent was Cottonwood Creek. These segments occur as both single and multiple ridges that probably reflect fluctuations in lake level and/or wave energy. Where transverse structures are evident, these ridges indicate upward construction attributable to transgressive lake waters. A second, more modest, series of ridges occurs about 0.5 km west of the northwest margins of the playa.

Table 2. Dating analyses of Lake Thompson sediment.

Sample number[1]	Laboratory number[2]	Measured radiocarbon age (years BP)[3]	13C/12C ratio (0/00)[4]	Conventional radiocarbon age (years BP)[5]
RW2@9	Beta 166446	6770 ±40	–21.4	**6830 ±40**
RW2@17	Beta 166447	17540 ±70	–21.6	**17600 ±70**
RW2@20	Beta 165108	20190 ±70	–23.3	**20220 ±70**
RW2@39	Beta 165110	21330 ±80	–24.2	**21340 ±80**
RW2@43	Beta 166448	30810 ±340	–21.9	**30860 ±340**
RW2@54[6]	Beta 166449	18530 ±80	–24.6	18540 ±80
TL1@15	Beta 166450	20150 ±90	–22.6	**20190 ±90**
TL1@30	Beta 166451	29550 ±280	–23.6	**29570 ±280**
TL1@46	Beta 166452	29090 ±260	–21.9	**29140 ±260**
TL1@61[6]	Beta 166453	25830 ±200	–23.7	25850 ±200

All sample ages reported here were based on the Accelerator Mass Spectrometry (AMS) Technique, conducted on organic sediment containing at least 300 µg of final carbon after pretreatment and acid washes. The AMS technique was used because, after visual inspection and pretreatment, the samples contained insufficient final carbon for the more usual Radiometric Technique. Pretreatment of other samples submitted revealed insufficient final carbon (<300 µg) for AMS analysis and are therefore not reported here.

1. Sample Number refers to coring location and depth of sample in feet from surface; e.g., RW2@9 is a sample from the Rosamond West No. 2 core at a depth of 9 ft; TL1@46 is a sample from the Thompson-Lancaster Boulevard No. 1 core at a depth of 46 ft (core logs were initially recorded in feet for compatibility with drilling operations; all measurements were subsequently converted to the metric system).

2. Laboratory Number refers to the reference accorded each sample by the processing laboratory, Beta Analytic Inc., Miami, FL. For consistency, this laboratory was used for all analyses. The AMS analyses were conducted by Beta Analytic in conjunction with its consortium laboratory partners in the U.S., England, Switzerland, the Netherlands, Germany, and New Zealand.

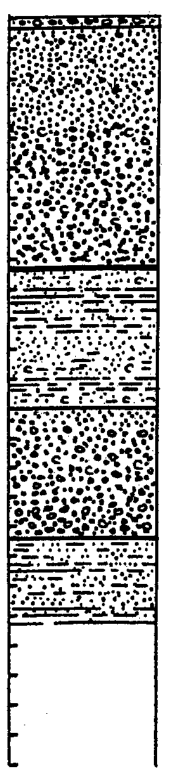
3. Measured Radiocarbon Ages are reported as radiocarbon years before present (BP) where "present" = 1950 AD. By international convention, the modern reference standard is 95% of the C14 content of the National Bureau of Standards' oxalic acid, calculated using the Libby C14 half-life of 5568 years. Quoted errors represent one standard deviation (68% probability) and are based on combined measurements of the sample, background, and modern reference standards.

4. Measured 13C/12C Ratios were calculated relative to the PDB-1 international standard.

5. Conventional Radiocarbon Ages (RCYBP) are obtained after applying C13/C12 corrections, normalized to –25 o/oo, to the Measured Radiocarbon Age. These ages are the most appropriate for comparative analysis and, in the ages reported above, are not calibrated to calendar years.

6. Ages for samples RW2@54 and TL1@61 are significantly out of stratigraphic sequence. They were analyzed separately after the other samples and may have become contaminated. They are discounted for discussion purposes.

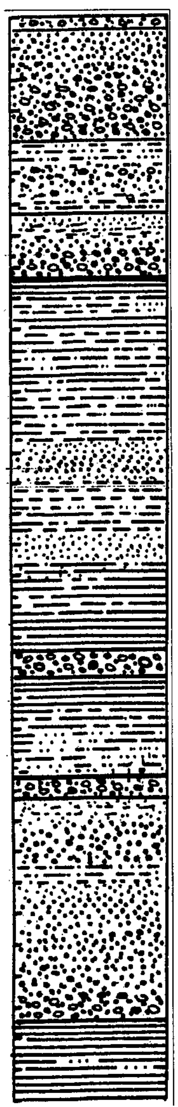
Table 3. Profile of Core RW1 beneath Rosamond West Beach Ridge. The surface elevation of the beach ridge at zero is 701 m above sea level. The mean elevation of nearby Rosamond Dry Lake is 693 m (or 8 m core depth).

Depth (m)	Depth (ft)	Stratigraphy and lithology	Grain size	Munsell color	14C age	Interpretation
0	0		cs-g	5Y 7/2		surface lag deposit
	2					
	4		cs	5Y 5/2		beach
	6		ms-cs-fg			
	8		ms-cs-fg, ca	5Y 5/2		
3	10		cs-fg	5YR 5/4		
	12		ms-cs-fg, mn			beach
	14		cs, ca	5Y 7/2		
	16		cs, ca	5Y 5/2		
	18		slcl-fs, ca	5Y 3/2		
6	20		fs-ssl	5Y 6/1		shallow lake -
	22		ssl-fs			lake nearshore
	24		slcl-ssl, ca	5Y 4/1		
	26		ssl, ca	5Y 4/1		
	28		ms-cs-fg	5Y 6/1		
9	30		cs-fg, ca			stream-beach
	32		slcl, cs	5GY 4/1		continuum
	34		cs-fg			
	36		sls-fs			
	38		slcl-ssl, cs	5GY 4/1		deeper lake
12	40		cl, slcl, fs			
	42					[bottom of core]
	44					
	46					
	48					
15	50					

Notation:

g	gravel: mg - medium gravel, fg - fine gravel
s	sand: cs - coarse sand, ms - medium sand, fs - fine sand, sls - silty sand
sl	silt: ssl - sandy silt, clsl - clayey silt
cl	clay: slcl - silty clay
ca	significant carbonate lenses and nodules
mn	manganese precipitation

Table 4. Profile of Core RW2 beneath Rosamond West Beach Ridge. The surface elevation of the beach ridge at zero is 701 m above sea level. The mean elevation of nearby Rosamond Dry Lake is 693 m (or 8 m core depth).

Depth (m)	Depth (ft)	Stratigraphy and lithology	Grain size	Munsell color	14C age	Interpretation
0	0		fs-cs-fg	10YR 6/6		surface lag deposit
	2		ms-cs	10YR 6/6		
	4		ms-cs-fg	10YR 7/4		beach
	6		ms-cs-fg			
	8			10YR 4/2		
3	10		sls, cs-fg		6830 ±40	back-barrier lagoon
	12		ssl-fs			shallow estuary
	14		sls-fs	10YR 7/4		basal beach
	16		ms-cs-fg			
	18		cl-clsl-ssl-fs	5GY 4/1	17600 ±70	
6	20		cl-sl	5Y 4/1		
	22		clsl-ssl	5Y 4/1	20220 ±70	
	24			5GY 2/1		lake of variable
	26		cl-slcl-sl-fs	5GY 2/1		depth; some
	28		sl-fs-ms			rhythmicity
9	30					
	32		sl-fs, slcl, ca	5Y 5/2		
	34		sl-fs			
	36		slcl-fs	5Y 5/2		
	38		slcl	5GY 4/1		
12	40		cl		21340 ±80	
	42		cs-fg-mg			stream input
	44		cl	5GY 4/1	30860 ±340	
	46		cl-slcl-ssl	5GY 4/1		deep lake
	48		sls			
15	50		ms-cs-fg, ca			stream input
	52		sls-fs			
	54		ms-cs	5Y 5/2	*?18540 ±80*	
	56		clsl-fs-ms			shallow lake
	58		ms-cs			
18	60		ms-cs	5Y 7/2		
	62		ms-cs			
	64		ms-cs-fg			stream input
	66		cl, ca	5B 5/1		
	68		cl, fs, mn			deep lake
21	70					[bottom of core]

Notation:

g	gravel: mg - medium gravel, fg - fine gravel, mg - medium gravel
s	sand: cs - coarse sand, ms - medium sand, fs - fine sand, sls - silty sand
sl	silt: ssl - sandy silt, clsl - clayey silt
cl	clay: slcl - silty clay
ca	significant carbonate lenses and nodules
fe	iron precipitation; mn - manganese precipitation

The beach ridge complex is composed mostly of sand and fine gravel, poorly sorted, generally massive, impregnated by secondary carbonate, often as nodules, and yellowish orange to grayish orange in color. Quartz sand is predominant. Individual grains are angular to subangular but rarely sub-rounded. These features are consistent with a relatively high-energy lakeshore environment adjacent to fluctuating inputs of fluvial sediment from streams draining from the Tehachapi Mountains farther west. No shelly debris was identified, although it may have been leached and reconstituted as pedogenic carbonate, and such vegetal matter as occurred was related to the root systems of modern plants.

Core RW2 revealed cohesive silty fine sand, grayish olive in color, between 2.4 and 3.7 m deep. This is interpreted as a back-barrier lagoon deposit that was later transgressed by the uppermost beach-ridge. This silty sand contained organic sediment that yielded a conventional radiocarbon (AMS) age of 6830 ±40 years BP, suggesting that the former lake rose to a highstand in mid-Holocene time.

The above beach-ridge sequence ended abruptly downward at a depth of 5.0 m, where it lay on hard silty clay with variable admixtures of clay, sandy silt, and fine sand, dark greenish gray to olive gray in color. This sediment is indicative of a lacustrine environment. Organic sediment near the top of this unit, from a depth of 5.18 m, yielded a conventional radiocarbon (AMS) age of 17,600 ±70 years BP. The abrupt truncation of this unit at 5.0 m, and the existence of sediment only 6830 years BP little more than 2 m above, suggests an erosion surface from which any overlying lake beds have been removed by deflation.

The remaining portions of core RW1 to its base at 12 m, and of core RW2 to its base at 21 m, are typical of sedimentation in a lake of variable depth characterized by episodes of coarse fluvial input and shallowing to a level where wave action could rework available sediment. Typical lake sediment comprises mostly silty clay, sandy silt, silty sand, and fine sand, dark greenish gray to light olive gray in color. True clay beds are less common but appear in both cores around 12 m and, in the deeper core, RW2, between 12.80 and 14 m and again below a marked boundary at 19.75 m to the core base at 21 m. The clays are typically olive gray to bluish gray in color, indicative of the "blue clays" observed in the well logs of earlier workers. Fluvial sediment is typically medium to coarse sand and fine gravel, notably in a prominent seam containing quartz and volcanic pebbles just below 12 m, between 15.2 and 15.70 m, and in a coarse, fining-up sequence above the boundary at 19.75 m.

Organic sediments at 11.9 and 13.1 m in core RW2 have yielded conventional radiocarbon (AMS) ages of 21,340 ±80 and 30,860 ±340 years BP, respectively. This continues the logical increase of age with depth found at

higher levels. A further AMS age of 18,540 ±80 years BP from a depth of 16.5 m is problematic and may reflect contamination. Based on the ages obtained higher in the sequence, sediment in this core below 15 m may well exceed the age range of radiocarbon dating.

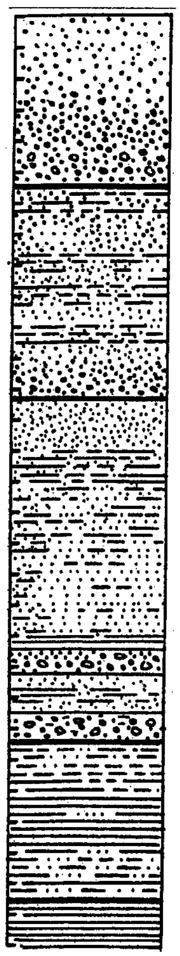
Thompson-Lancaster Playa (TL1)

The relatively deep TL1 core, reaching a maximum depth of 34 m, was dominated by lacustrine silts and clay interspersed with coarser units indicative of fluvial and aeolian inputs into water of variable depth. There are no recognizable beach deposits, nor are any to be expected at this site near the deepest part of Lake Thompson. From the playa surface down to about 3 m, the sequence begins with a coarsening-downward sequence of medium and coarse sand and fine gravel, brown to yellowish brown or grayish brown, indicative of fluvial and aeolian inputs into an exposed playa environment. From 3 to nearly 8 m, the sequence comprises finer sediment, mostly in the silty clay to fine sand range and olive brown, indicative of deposition in shallow water. Organic sediment at 4.6 m from this unit yielded a conventional radiocarbon (AMS) age of 20,190 ±90 years BP.

From 8 to about 14 m are sequences of silty clays, sandy silts, silty sands, and fine sands, with occasional seams of coarser sand and fine gravel, mostly light to moderate olive brown to light olive gray. These sediments indicate deposition in a lake of variable depth that was invaded from time to time by stream sediment and more or less continuously subject to airfall deposition. The deposits are often laminated but sometimes disturbed by bioturbation or bottom currents. Organic sediment from 9.1 and 14 m yielded conventional radiocarbon (AMS) ages of 29,570 ±280 and 29,140 ±260 years BP, respectively.

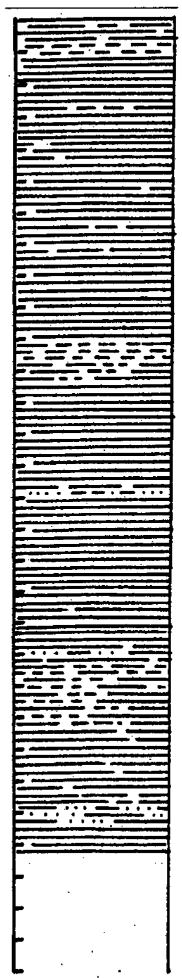
From 14 m to the base of the core at 34 m, the sequence is dominated by clays, with seams of silty clay and sandy silt towards the top. These clays and silty clays are often finely laminated. They vary from brown to yellowish brown, probably indicative of oxidation, to olive gray and grayish green, probably indicative of anoxic conditions. The character of the deposits suggests deposition of fine suspended sediment under tranquil conditions in a deep lake. Even so, the alternation of brownish and greenish coloration suggests frequent oscillations of lake level during the period of deposition. Although a curious AMS age of 25,850 ±200 years BP was obtained from organic sediment at 18.6 m, it is more likely, from the dated evidence above, that this lake predates the useful range of radiocarbon dating.

Table 5. Profile of Core TL1 (Thompson-Lancaster Playa) in Buckhorn Corridor. The surface elevation of the playa at the coring site is 693 m. The mean elevation of nearby Rogers Dry Lake is 692 m (or 1 m core depth).

Depth (m)	Depth (ft)	Stratigraphy and lithology	Grain size	Munsell color	14C age	Interpretation
0	0		s	10YR 5/4		playa crust
	2		fs-ms, ca			
	4		ms			fining-up
	6		ms-cs			stream-dune
	8		cs	10YR 5/4		complex
3	10		ms-cs-fg			
	12		ms, slcl	5Y 4/4		
	14		fs-ms			lake-stream-dune
	16		slcl-ssl-s		20190 ±90	complex
	18		slcl, sl-fs			
6	20		fs, cl-sl			
	22		fs	5Y 4/4		
	24		fs-ms-cs			
	26		fs			variable lake,
	28		fs, slcl	5YR 5/6		fluvial/aeolian
9	30		fs, slcl		29570 ±280	inputs;
	32		ssl-sls	5Y 4/4		laminated or
	34		slcl-sls-fs			bioturbated;
	36		ssl-sls-fs			locally oxidized
	38		sls-fs			
12	40		sls-fs, cl			
	42		ms-cs-fg			
	44		fs, cl	5Y 5/6		
	46		cl, cs-fg, fe	5Y 5/2	29140 ±260	
	48		ssl			
15	50		cl-slcl	5Y 5/2		
	52		cl-ssl			
	54		cl, fs			deeper lake
	56		sls-fs, cl	5Y 5/2		
	58		cl			
18	60		cl	5YR 4/2		deep lake

Notation:		
	g	gravel: mg - medium gravel, fg - fine gravel
	s	sand: cs - coarse sand, ms - medium sand, fs - fine sand, sls - silty sand
	sl	silt: ssl - sandy silt, clsl - clayey silt
	cl	clay: slcl - silty clay
	ca	significant carbonate lenses and nodules
	mn	manganese precipitation

Table 5 (cont.). Profile of Core TL1 (Thompson-Lancaster Playa) in Buckhorn Corridor.

Depth (m)	Depth (ft)	Stratigraphy and lithology	Grain size	Munsell color	14C age	Interpretation
18	60		cl	5YR 4/2		
	62		cl-slcl	10YR 5/4	*?25850 ±200*	
	64		cl			deep lake
	66		cl	5YR 5/4		
	68		cl			
21	70		cl	10YR 5/4		
	72		cl	5Y 5/2		
	74		cl	5G 5/2		
	76		cl			
24	78		cl			
	80		cl			
	82		slcl	10YR 5/4		deep lake,
	84		cl	10YR 5/4		deposits often
	86		cl			well laminated;
27	88		cl	5YR 5/6		locally oxidized
	90		cl			
	92		cl	5YR 5/6		
	94		cl			
	96		cl	5YR 5/6		
30	98		cl			
	100		cl	5YR 4/4		
	102		cl-slcl	10YR 4/2		deep lake
	104		cl-slcl	5YR 4/4		
	106		cl			
33	108		cl			
	110		cl, s	5YR 4/4		
	112		cl			
	114					[bottom of core]
	116					
36	118					
	120					

Notation:

g	gravel: mg - medium gravel, fg - fine gravel
s	sand: cs - coarse sand, ms - medium sand, fs - fine sand, sls - silty sand
sl	silt: ssl - sandy silt, clsl - clayey silt
cl	clay: slcl - silty clay
ca	significant carbonate lenses and nodules
mn	manganese precipitation

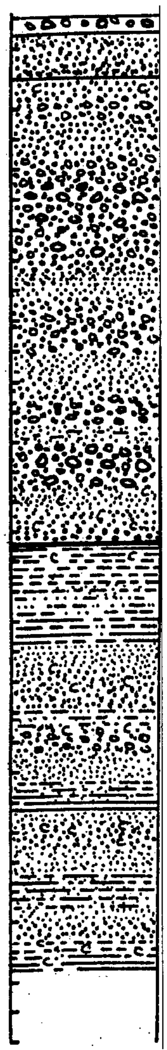
Rogers East Beach Ridge (RE1)

The Rogers East site was chosen to penetrate the massive beach ridge at the northeast end of Rogers Dry Lake. This it did, but the underlying deposits are more difficult to interpret than those in the preceding cores, primarily because they are dominated by sand, with a paucity of clay and silt that would indicate former deep lake conditions. This is perhaps unsurprising because the barrier-beach and dune complex was formed at the downwind end of former Lake Thompson, where both onshore wave climate and aeolian inputs from upwind sources would be strongest.

From a surface elevation of 701 m above sea level, the core first penetrated up to 0.04 m of coarse gravels, the lag deposit of a formerly higher beach ridge, and then 1.0 m of well-sorted, yellowish brown aeolian sand. From there to a depth of 8 m, the core penetrated a massive accumulation of poorly sorted, light brown to grayish orange, medium to coarse sand with numerous gravel clasts 1–2 cm in diameter. This is the late Holocene beach ridge, but reflecting its higher energy wave climate and thus effective wave base, its foundations descend much deeper than comparably aged beach ridges west of Rosamond Dry Lake.

The alternating sequence below 8 m, namely finer and coarser sands with occasional seams of silt and clay, appears to reflect the deposition of aeolian sand and silt in water of varying depth. The sediment is richly endowed with carbonate seams and nodules and varies from light brown to dark yellowish orange. Thus, the porosity and permeability of this sandy sequence has favored widespread weathering and reconstitution of carbonates. These facies are probably coeval with the silts and clays of the deeper lake farther west, but materials suitable for dating have yet to be identified.

Table 6. Profile of Core RE1 beneath Rogers East Beach Ridge. The surface elevation of the beach ridge at zero is 701 m above sea level. The mean elevation of nearby Rogers Dry Lake is 692 m (or 9 m core depth).

Depth (m)	Depth (ft)	Stratigraphy and lithology	Grain size	Munsell color	14C age	Interpretation
0	0		cs-g			surface lag gravel
	2		ms	10YR 5/4		dune
	4		cs, ca	5YR 5/6		
	6		ms-cs-fg			
	8					
3	10		ms-cs-fg	5YR 5/4		
	12		cs-fg-mg			
	14					beach–dune complex
	16					
	18			10YR 7/4		
6	20		fs-ms-cs, fe			
	22		fs-ms-cs-fg	10YR 7/4		
	24		fs-ms	10YR 7/4		
	26		ms-cs-fg			
	28		sl-fs-ms	5YR 5/6		[dune]
9	30		cs-mg-cg			
	32		fs-ms, ca			[dune]
	36		ms-cs, ca	5YR 5/6		
	38		slcl-clsl-sl, ca			
12	40		sl-fs	10YR 5/4		shallow lake with
	42		slcl-ssl			aeolian inputs
	44		fs			
	46		fs-ms, ca	5 YR 5/6		[dune]
	48		sls			
15	50		ms-cs-fg, ca			beach
	52					
	54		cl-sl-fs			shallow lake
	56		fs-ms, ca	10YR 6/6		[dune]
	58					
18	60		slcl-ssl-fs	10YR 5/4		shallow lake
	62		fs-ms	10YR 5/4		[dune]
	64		cl-sl, ca			shallow lake
	66					[bottom of core]
	68					
21	70					

Notation:

g	gravel: fg - fine gravel, mg - medium gravel, cg - coarse gravel
s	sand: cs - coarse sand, ms - medium sand, fs - fine sand, sls - silty sand
sl	silt: ssl - sandy silt, clsl - clayey silt
cl	clay: slcl - silty clay
ca	significant carbonate lenses and nodules; fe - iron precipitation

6 CLAY-MINERAL ANALYSIS

By Richard Yuretich

Clay-mineral analyses were conducted on selected core samples from beneath Lake Thompson to examine aspects of the sedimentary mineralogy that would elucidate depositional and climatic conditions in and around the former lake during the period of record identified by AMS dating, namely the past 30,000 years.

Methods

Samples were collected from core RW2 on the higher beach ridge west of Rosamond Dry Lake and from core TL1 in the Buckhorn corridor near Lancaster Boulevard. Samples for analysis were chosen to distribute them at approximately equal intervals along the cores and to intersect any notable changes in the stratigraphy. Preliminary drying of the sediment was done in an oven at 60°C. The dried sediment was crushed gently, weighed, and put in centrifuge bottles in a solution of sodium acetate and acetic acid buffered to a pH of 5.5. These samples were heated overnight at 60°C, then shaken to break up loose clumps, and dispersed using an ultrasonic dismembrator. The preparations were centrifuged and washed with distilled water to remove the acetate solution. A final centrifugation settled the >2-μm fraction to the bottom of the bottles, and the cloudy supernatant was transferred to a beaker and allowed to evaporate (at 60°C) until all the clays had formed a paste. The paste was smeared on glass slides to produce oriented mounts for X-ray diffraction analysis.

Clay minerals were identified by X-ray diffraction using a Siemens Type F goniometer and a Databox digital upgrade. Diffraction patterns were obtained using Cu*Kalpha* radiation, scanning from 2° 2θ to 30° 2θ with a step size of 0.05° and a counting time of 1 s. Samples were run after drying in air and then after solvating with ethylene glycol (Brown and Brindley 1980, Hardy and Tucker 1988). The relative abundance of clay minerals was determined by ratios of diffractogram peak height of the 001 diffraction line of each clay on glycolated samples (Griffin 1971). Although this does not provide a true estimate of the actual amount of each clay mineral, it is reliable for comparing relative changes among the samples. The clay minerals were identified primarily by basal (001) diffraction lines on glycolated specimens: smectite, 17 Å; chlorite, 14.2, 7, and 3.54 Å; illite, 10 Å; and kaolinite, 7 and 3.58 Å. Semiquantitative estimates of mineral abundance were based on integrated peak areas determined via the computer program Jade (version 2.0). The relative percentages of the clay

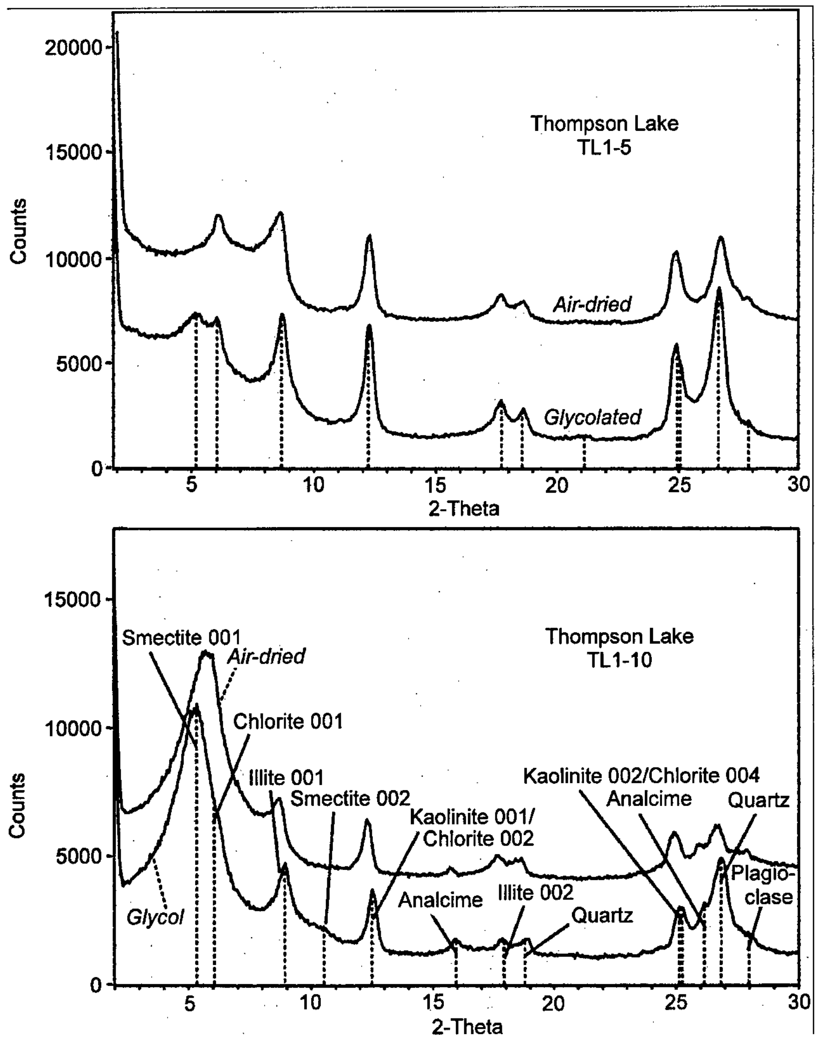


Figure 5. Representative diffractograms of clay minerals from Core TL1.

minerals were determined using the empirical weighting factors of Biscaye (1964, 1965). Although this method does not give a truly quantitative measure of different clay-mineral types, it provides a useful guide to relative changes within a sequence (Menking 1997).

Results and Discussion

The clay minerals in the cores consist of smectite, illite, kaolinite, and chlorite (Fig. 5). In addition, quartz and plagioclase feldspar are common, and the mineral analcime occurs in some samples from core TL1. Proportions of the clay

Table 7. Abundance of clay minerals in Lake Thompson cores RW2 and TL1.

Sample	Depth (m)	% Smectite	% Illite	% Kaolinite	% Chlorite
RW2-5	7.32	59	25	10	6
RW2-6	7.65	50	38	8	4
RW2-12	13.14	69	22	6	2
RW2-13	13.84	70	25	4	1
RW2-19	19.99	66	22	8	4
RW2-21	20.97	79	12	6	2
Average		66 ±10	24 ±8	6 ±2	4 ±2
TL1-3	5.85	56	23	11	10
TL1-5	8.23	13	58	17	13
TL1-7	11.80	14	50	22	14
TL1-8	13.72	48	23	15	15
TL1-9	15.00	54	35	7	4
TL1-10	16.18	58	32	6	4
TL1-11	17.65	32	54	8	7
TL1-12	18.84	25	58	12	5
TL1-13	20.33	49	41	5	4
TL1-14	22.62	52	38	7	3
TL1-16	26.30	23	61	9	7
TL1-17	28.29	37	49	8	5
TL1-18	29.66	34	50	9	7
TL1-19	30.88	26	59	7	8
TL1-20	32.00	20	64	9	7
TL1-21	33.92	34	56	6	5
Average		36 ±15	47 ±13	10 ±5	7 ±4

minerals vary between the cores and stratigraphically down each core (Table 7). In general, the RW2 core has a greater abundance of smectite than the TL1 core, but the latter core has greater fluctuations in the relative percentages with depth. Smectite is used as an indicator of the magnitude of these fluctuations because it is often the most sensitive to environmental changes, and since all clay minerals together total 100%, an increase in one type will be balanced by a decrease in the others. Smectite tends to increase with depth in core RW2, whereas the trend is reversed in core TL1 (Fig. 6 and 7). This trend in core TL1 is by no means smooth but is superimposed on large changes in smectite abundance from one stratigraphic horizon to the next. The mineral analcime is found in core TL1 in all samples from depths greater than 16 m.

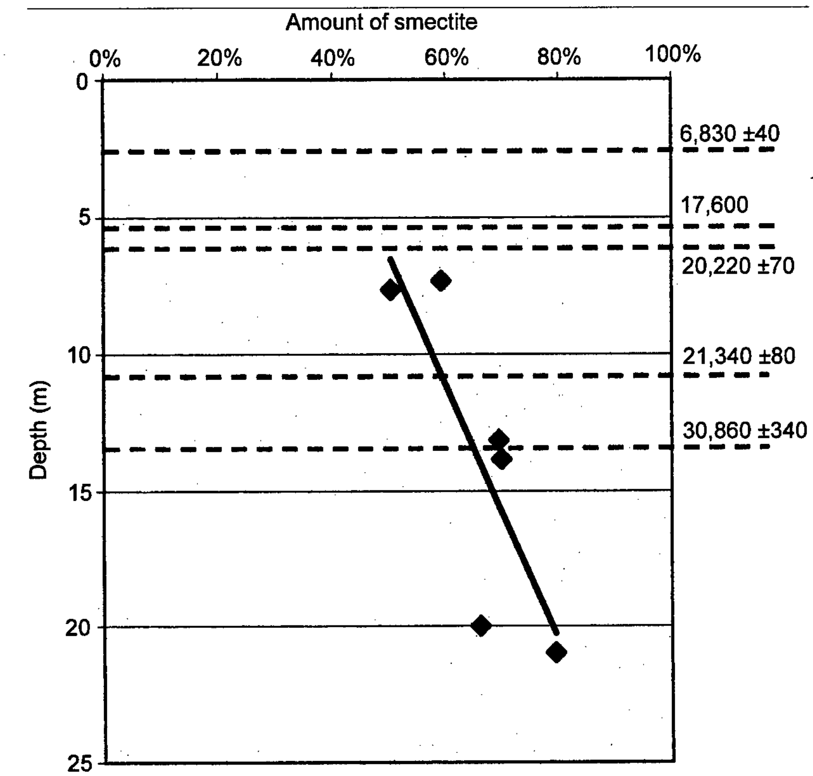


Figure 6. Percent smectite in Core RW2, Rosamond West Beach Ridge. The horizontal dashed lines represent AMS radiocarbon ages shown in the right-hand margin.

The general clay-mineral assemblages are similar to those found in a previous investigation of clay minerals from beneath Rogers Dry Lake (Tassier-Surine 1999).

Smectite is commonly produced in soils by the breakdown of rock-forming aluminosilicate minerals under fluctuating moisture conditions. If leaching of the parent materials becomes greater, kaolinite is usually favored. Illite, which is usually derived from mica, is most stable under cooler or drier conditions. Cold climates favor the preservation of chlorite, which is found as a primary mineral in many low-grade metamorphic rocks. Consequently the relative proportions of these minerals can be used as a guide to weathering intensity or climatic conditions. Sediments on the modern playa surface of Rogers Lake have illite as the most abundant mineral, with relatively low smectite (<1–23%), which is indicative of the arid conditions prevalent in the basin and sediment source area. Clay minerals are also subject to post-depositional transformation, particularly in situations where saline or alkaline fluids may form by evaporative concentration

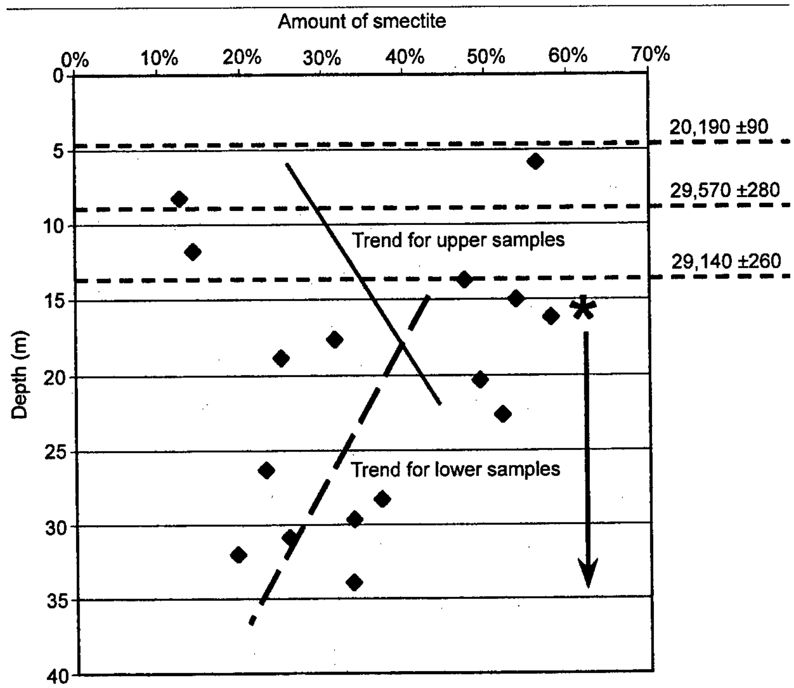


Figure 7. Percent smectite in Core TL1, Buckhorn Corridor. The asterisk and arrow show the zone containing analcime. The horizontal dashed lines represent AMS radiocarbon ages shown in the right-hand margin.

of surface and groundwater. Under these conditions, smectite can react with silica-rich fluids to form a zeolite, such as analcime (Hay et al. 1991).

Tassier-Surine (1999) concluded that sediments in an earlier core from beneath Rogers Lake that contained abundant smectite were representative of a wetter, more humid climate with large amounts of runoff, conditions that would aptly describe the environment of Lake Thompson during its maximum late Pleistocene highstand. The warm and arid playa environment that exists today is characterized in the core she studied by relatively low smectite, yet with frequent fluctuations in abundance that reflect repeated wet and dry intervals. During the final stages of such dry intervals, the evaporating silica-rich water on the playa surface reacts with smectite in the sediments to form the zeolite analcime.

Using these relationships as a guide, we can give a preliminary interpretation of the clay-mineral composition in the collected cores. The relatively high smectite in core RW2 from beneath the Rosamond West high beach ridge is consistent with deposition in a large lake under humid conditions. In addition, the trend in the core suggests that the climate in the lake basin was becoming drier

from some time before 30,000 years BP until the cessation of the lake record in this core at 17,600 years BP (Fig. 6).

The interpretation of the patterns in core TL1 is somewhat less certain. With the exception of the uppermost sample at 5.9 m in the core, there is an upward decrease in the abundance of smectite from a depth of approximately 16 m. This interval corresponds approximately in time to the same zone in core RW2 and could reflect the same climatic influences, namely drying after 30,000 years BP. However, the data from the deeper samples show a reversal of this trend, exhibiting a decrease in smectite abundance with depth. In addition, the mineral analcime is present in all samples below a depth of 16 m in this core (Fig. 7).

The data from the lower part of core TL1 could indicate the existence of a more saline, alkaline lake in the basin at some point prior to 30,000 years ago. However, some caution is necessary because post-depositional modifications by percolating groundwater could influence the mineralogy. The modern water table beneath Rosamond and Rogers Dry Lakes has been reported at a depth of 15 to 20 m (Motts and Carpenter 1970). Persistent evaporation in the zone of capillary action could form the zeolites in question, but further analyses are needed to verify the origin of the sedimentary minerals and to evaluate their implications for the environmental evolution of the Lake Thompson basin.

7 CONCLUSION

The foregoing discussion has reported on all three phases of the project designed to understand better the character and devolution of Lake Thompson. Phase I dealt with Rosamond Dry Lake, Phase II with Buckhorn Dry Lake and Mojave Creek, and Phase III with Rogers Dry Lake and included a modest coring program designed to elucidate the geochronology of the former lake system. Collectively these projects comprise both spatial and temporal components.

From a spatial perspective, an original classification scheme based on field evidence was developed for the geomorphic and lithostratigraphic units recognized in and around Lake Thompson. Using this scheme, a series of maps were prepared as aerial photographic overlays for all portions of Lake Thompson within the confines of Edwards Air Force Base, and a color-coded map of the Lake Thompson system was prepared. The final map, entitled *Geomorphology and Quaternary Geology of Lake Thompson within Edwards Air Force Base, California,* was prepared by Antony R. Orme in association with the U.S. Army Corps of Engineers.

In terms of spatial geomorphology, the area of former Lake Thompson is very complex. Seven major geomorphic and lithostratigraphic units are recognized, subdivided into 17 intermediate units, some of which are further subdivided into 22 lesser units. Certain landforms, such as exposed beach ridges and lake plain deposits, are readily identified in the field and from remote sensing imagery, except where concealed or destroyed by human activity. Most other features grade into or interfinger with one another, and only careful field investigation reveals their relationships. For example, the former lake plain is commonly veneered with aeolian sand, nearshore sediment, and alluvial deposits that have been reworked by wind and water into new forms. These have in turn been degraded and their sediment partly removed by a continuation of geomorphic processes in the absence of fresh sediment supplies. Overall, much of the natural system that came into existence as Lake Thompson dried out has in turn been eroded and redistributed by continuing aeolian and alluvial processes and further modified by human activity.

The most important geomorphic units from a spatial and ecological perspective are (1) the bare modern playas of Rosamond, Buckhorn, and Rogers Dry Lakes; (2) the emergent beach ridges and relatively featureless bottom deposits of the former lake floor; (3) the sand sheets and dunes of the aeolian landscape that developed as the former lake floor desiccated and that in turn have been degraded and their sands removed downwind; and (4) the alluvial channels and fan deposits that interfinger with the lacustrine and aeolian units around the

former lake margin, the more recent a testimony to continuing, if reduced, fluvial processes and occasional floods. Lesser units comprise (5) talus slopes and colluvial surfaces of limited extent, and (6) bedrock uplands, mostly granitic, that flank and sometimes descend into, or emerge from, the former lake. Historic human use of the former lake floor has imprinted (7) artificial (anthropogenic) terrain onto the natural system, in places erasing the latter. Each of these units is associated with a distinct ecological signature, most readily distinguishable between sandy materials of mostly shoreline (beach ridge), aeolian, and fluvial provenance, and silty and clayey materials of the former lake floor.

From a temporal perspective, this study has presented for the first time a chronology for the late Quaternary devolution of the Lake Thompson system. Earlier studies, including a variety of borehole evidence, had indicated the presence of a former lake beneath the Antelope Valley, but there had been no indication of its age, largely because there is virtually no datable material such as molluscan debris at or near the surface. The present study describes a modest coring program that yielded detailed information on subsurface stratigraphy and lithology and, applying accelerator mass spectrometry to microscopic organic sediment, presents a series of radiocarbon ages that address this problem. Four cores were retrieved, two from depths of 12 and 21 m beneath a beach ridge west of Rosamond Dry Lake, one from a depth of 34 m beneath a playa near the center of former Lake Thompson, and one from a depth of 20 m beneath the massive beach ridge northeast of Rogers Dry Lake.

In essence, based on seven secure radiocarbon ages, a fluctuating but usually deep lake existed in the Antelope Valley between at least 30,860 and 17,600 years BP. This lake was subject to episodic incursions of flood waters from the Tehachapi and San Gabriel Mountains and to intervals of oxidation weathering of its bottom sediment, but complete desiccation seems unlikely. Stratigraphic evidence from greater depth, as yet undated, shows that this lake existed more or less continuously for several millennia prior to 30,860 years BP. The abrupt upward termination of lacustrine stratigraphy at a depth of 5 m (696 m above sea level) in the RW2 core, and at 3 m (690 m above sea level) in the TL1 core, suggests that lacustrine deposition may have continued after 17,600 years BP but that the record was subsequently erased by erosion. The two cores west of Rosamond Dry Lake, combined with geomorphic and structural evidence, indicate a subsequent lacustrine transgression over these exposed lake beds, leading to deposition of the barrier-beach ridge complex readily apparent in the present landscape. An age of 6830 years BP from probable back-barrier lagoonal silts within this complex suggests that this transgression continued into mid-Holocene time.

Clay-mineral analyses from cores RW2 and TL1 confirm this interpretation with respect to the relative proportions of smectite, illite, kaolinite, and chlorite. The relatively high smectite content in core RW2 is consistent with deposition in a large lake under humid conditions. The trend in the core suggests that the climate in the lake basin was becoming drier from sometime before 30,860 years BP until the cessation of the lake record at 17,600 years BP. The clay-mineral record from core TL1 is less certain, but again there is an upward decrease in the amount of smectite from before 29,140 to nearly 20,190 years BP. At greater depth, however, smectite abundance also decreases, suggesting the existence of a more saline, alkaline lake at some point prior to 30,000 years BP.

In short, a relatively deep lake, Lake Thompson, existed in the Antelope Valley from before 30,860 years BP to sometime after 17,600 years BP, subsequently wholly or partly desiccated but later returned, or at least transgressed from a lower level, to construct beach ridges beyond the margins of the modern playas. Following this latter stage, the lake again desiccated and the lake floor was reshaped largely by aeolian activity and dune formation. As sources of sand diminished with the loss of fluvial sediment inputs in an increasingly arid climate, these dunes were in turn degraded and their sand removed downwind. Thus, apart from a thin veneer of recent aeolian sand and silt, the floor of Lake Thompson and its superposed dunes are largely relict features from earlier geomorphic regimes.

Evidence of other lakes in the Great Basin and Mojave Desert correlates to some extent with the above scenario. In Utah, for example, Lake Bonneville began rising around 30,000 years BP and reached a maximum highstand around 16,000 years BP but, for a variety of reasons, had fallen to below historic levels of the present Great Salt Lake by 12,000 years BP. It then rose to slightly higher levels in the terminal Pleistocene and has since fluctuated during the Holocene (Currey et al. 1983). In northwest Nevada, Lake Lahontan behaved somewhat similarly (Benson et al. 1990). Farther south, Death Valley sustained a relatively deep perennial lake between 35,000 and 10,000 years BP and then desiccated (Lowenstein et al. 1999). The Eastern California Lake Cascade, most notably Lake Owens north of Lake Thompson, reached a maximum highstand around 22,000 to 18,000 years BP, then fell before oscillating in the terminal Pleistocene, and generally falling in the Holocene (Orme 2002). Lake Mojave (present Silver and Soda Lakes) in the eastern Mojave Desert, though essentially a Pleistocene lake, experienced fluctuations related to episodic wetter intervals during the later Holocene (Enzel et al. 1989).

Further investigations are needed to confirm the details of the late Quaternary devolution of Lake Thompson and to decipher the record of the lake's existence before 30,000 years BP. Ideally, a relatively wide core should be retrieved from

near the former lake's center, deeper than the 34-m core from TL1 discussed here. Also, a further series of shallow cores should be retrieved from the beach ridges and immediately subjacent lake beds, covering approximately the last 15,000 years, to refine the terminal Pleistocene and Holocene chronology. Such information would be valuable to the continued management of the former lake ecosystem, particularly as it would refine the relative importance of lacustrine, fluvial, and aeolian processes, and therefore of climate change, to the shaping of the developing post-lake environment and problems associated with its flood potential, groundwater resources, and subsidence.

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14. ABSTRACT

In late Pleistocene time, Lake Thompson rose to 710 m above sea level and covered 950 km^2 of the western Mojave Desert, California. During Holocene time, the lake desiccated and is today represented mainly by Rogers, Rosamond, and Buckhorn Dry Lakes, which cover 200 km^2 of Edwards Air Force Base. Elsewhere the former lake basin is characterized by exposed lake beds and beach ridges or mantled by aeolian and fluvial deposits. This study reports on the spatial and temporal components of former Lake Thompson. The spatial dimension identifies seven major geomorphic and lithostratigraphic units within the former lake basin, of which the most important are the modern playa, former lake system, aeolian mantle, interfingering fluvial deposits, and various bedrock outcrops. These units and their subdivisions are presented on a map entitled Geomorphology and Quaternary Geology of Lake Thompson within Edwards Air Force Base, California. The temporal component is represented by a chronology of Lake Thompson based on accelerator mass spectrometry dating of the stratigraphic sequence. Although a former deep lake beneath the modern dry lakes had long been inferred from borehole data, its age and development remained unknown. The present study recovered four cores for stratigraphic and sediment analysis and dating. Ages for the deep lake range from 30,000 to 17,000 BP, a humid interval typified by frequent inputs of fluvial sediment. After 17,000 BP, the lake began to desiccate, and its exposed floor was lowered by deflation. However, shallow perennial lakes returned during latest Pleistocene and early Holocene time, prior to the present phase of desiccation. Clay minerals from the cores support this scenario. High smectite values reflect deposition in a large lake under humid conditions around 30,000 BP, followed by diminishing smectite as conditions became drier. A more saline, alkaline lake existed under drier climatic conditions before 30,000 BP. The later phases of lake devolution during Holocene time have seen lake segmentation as shallow-water waves and currents generated a sequence of beach ridges around contracting lakes. These ridges became mantled with aeolian sand, but as fluvial sediment inputs diminished, these dunes were degraded and their sand removed downwind. The roots of these dunes survive as yardangs. Understanding this complex system provides a valuable tool for management of the lake basin, including its flood hazards, groundwater resources, blowing dust potential, subsidence problems, and ecology.

15. SUBJECT TERMS

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Mojave Desert
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